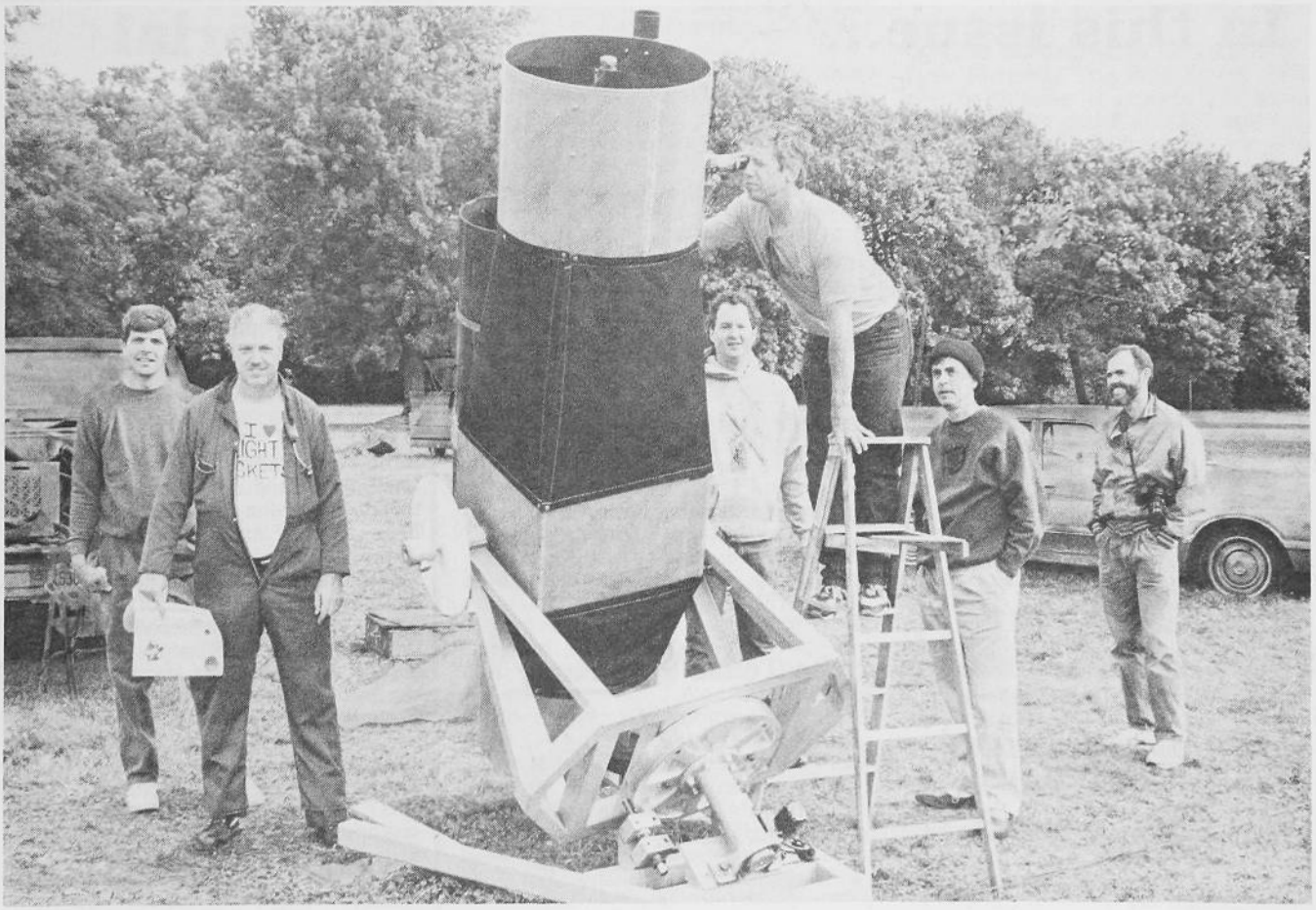
TELESCOPE MAKING 42

ISSN 0190-5570

The magazine *for*, *by*, and *about* telescope makers! **Fall 1990**



•Three Summer Gatherings•
•Texas Star Party•Stellafane•
•and AstroFest•

Telescope Making #42

The magazine *for*, *by*, and *about* telescope makers!

Editor: Richard Berry
Associate Editor: Peter Ceravolo

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Cover: On the "morning after" at AstroFest, when just about everyone else had packed up and gone home, members of the Chicago Astronomical Society were still observing Jupiter. Dan Joyce holds the prize certificate his instrument won, while Carl Buzzard peers through the eyepiece.

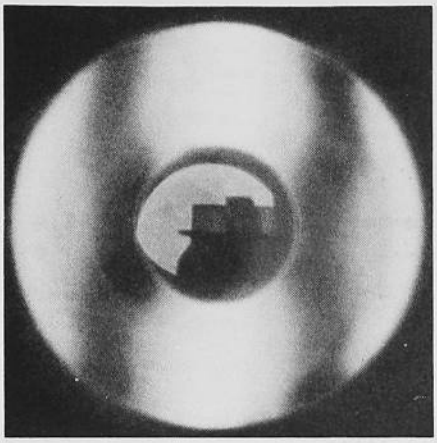
Editorial

Here at Kalmbach, we've been very busy these last four months. The cause is our new launch, EARTH magazine. EARTH has somewhat indirectly grown from ASTRONOMY, and EARTH takes advantage of the expertise we at ASTRONOMY have in science popularization. The long and short of it, however, is that we've had just enough brains, hands, and computers on hand to create ASTRONOMY and EARTH—but no more. That condition is quite temporary, and TM will soon be back on schedule. Much of the editorial work for *TM#43* has already been done, and it should follow *TM#42* quite closely.

Still hanging over the world of astronomy is the specter of *HST*'s bum optics. Since we gathered the speculations in our *HST* story, the cause of the optical fabrication error has been pinpointed. The error stems from the misassembly of a reflective null corrector. Although such devices are routinely constructed to an accuracy of a few waves of light, *HST*'s null corrector had a gross spacing error of 1.2 millimeters. The corrector was still in the test room where it had been used at Perkin-Elmer/Hughes.

A backup primary mirror was made at Kodak—indeed, a representative of Kodak spoke about the making of that mirror at Stellafane about ten years ago—and that mirror was also tested with a reflective null corrector. But that set of null optics was apparently okay, and the mirror that Kodak made is a good one. Sigh!

A further frustration is that during the testing of the P-E/Hughes



Correction: In "The Nuances of Optical Testing," the photo on page 17 showing Ronchi bands was an interferogram. The correct photo is above.

primary, the opticians cross-checked the correction of the mirror with a refractive null tester. It showed the *HST* mirror's correction was wrong, but because they did not trust the refractive system (which may suffer from uncertainty in the refractive index of the glass), this clear indication of a problem was ignored.

On a happier note, those readers of *TM* who wish to write to Peter Ceravolo directly should take note of his new address:

Peter Ceravolo
Telescope Making
P.O. Box 27092
Gloucester, Ontario
K1J 9L9 CANADA

Peter handles stories that deal with optics and optical fabrication.

I'd welcome reader comments on Marschall Nunlist's letter in the column to the right, especially letters from the relative newcomers to *TM*. What confuses you in *TM*—and what kinds of stories do you especially like? For the old hand at telescope making, where are your interests in these days of microchips and servo systems? Does optics turn you on? Ray tracing? Fabrication? Assembly?

Or do the mechanics of telescopes grab your interest? Are you interested in equatorials, Dobsonians, or platforms? I'll be looking forward to your letters, and I'll run a representative sampling in the Letters column.

That's it until the next issue. Please take a look at our new EARTH magazine. I think you'll agree that it's a much-needed magazine.

Letters

Not Flat But Smooth!
Dear Richard/ I want to draw the attention of your readers to a possible source of confusion regarding autocollimating "flats." As Herbert Highstone points out in his letter (TM#41), mirrors used as autocollimators don't have to be perfectly flat. However, he doesn't clarify the fact that the difficulty of making such mirrors is not in keeping them flat but smooth. In order to test a mirror to 1/10-wave accuracy, an autocollimating mirror must have surface errors no larger than 1/20 wave (since their magnitude doubles on reflection). And that level of precision is not always easy to achieve!

Mladen Vranjican
232 Carrie Drive
Franklin, VA 23851

– Oops! Thanks to you and the many other readers who caught this oversight. And you are certainly correct that a 1/10-wave surface is not easy to make. Highstone's point, and I'm sure you'll agree, is that it's easier to make a 1/10-wave near-flat sphere with a curvature somewhere close to zero than it is to make a 1/10-wave perfectly-flat flat with a curvature of exactly zero.

Telescope Making for Everyone
Dear Mr. Berry/ I read with great interest all your Telescope Making articles, but particularly with respect to the mirror testing, fabricating optics, and so forth. S&T has virtually given up on this subject, and I know of no other publication even interested. So TM really stands alone in this field.

Your optical write-ups, however, tend to be advanced, even semi-professional, in level. I am writing you to ask whether occasional articles directed at least in part to more elementary mirror-making would attract a larger readership. I fear that we telescope makers are allowing the art of amateur mirror making to disappear, with the result that the ranks of amateurs will thin out and disappear.

Perhaps advanced TMs will cry "foul, we want more advanced articles." But shouldn't telescope makers want to ensure the continuation of telescope making and the creation of a new generation of interested people?

I expect that there must be pressure from commercial manufacturers to discourage amateur telescope making. But the fact remains that with a little patience an amateur can produce a better mirror than most presently offered for sale. Perhaps you and your magazine have the opportunity to rescue this art form of mirror making from oblivion.

In an attempt to find kindred spirits, I have joined clubs in the Cleveland area and now in eastern Massachusetts, notably the venerable Amateur Telescope Makers of Boston. I regret to say that actual telescope making is furthest from the club's thoughts!

Perhaps, after all is said and done, I may just be living in a world that no longer exists. Bob Cox and I "grew up" together as members of the Hayden Planetarium Optical Division. Bob continued in a successful career in optics, whereas I veered off into management consulting. I deeply mourn the loss of this old friend of so many years.

At heart, Bob Cox was always the dedicated amateur in the best sense of the word. It would be a pity if the object of his enthusiasm and spirit were allowed to fade away.

Marshall B. Nunlist
288 Mirick Road
Princeton, MA 01541

Optical Goldmine in Red Tanks?
Dear Richard/ The Wall Street Journal for October 8 reports the scrapping of Soviet and East bloc tanks for their metal. It dawned on me that these tanks should hold a treasure trove of optics, just as WWII surplus gear did.

Russian optics can be very good, the 236-incher notwithstanding. I will happily match my Russian MTO (Maksutov Tele Objective) against any contemporary German, Japanese, or American catadioptric for optical quality. If the Russkies follow precedent, their military optics should show a strong family resemblance to Carl Zeiss Jena work. Certain cameras used in the Salyut and Mir programs are almost certainly from CZJ.

Given the number of periscopes in an average tank, a modern day C&H Sales, Edmund Salvage, or A.S.C. could do telescope makers an invaluable service by looking into foreign surplus. (Middle men are already available to grease the skids: witness the clothing and kit gear already on the market here, everything from shirt-jacks from Odessa to AK ammo pouches).

I'd like to see an inexpensive alternative to the overpriced eyepieces of Japanese manufacture. While I don't really expect to see the return of ads proclaiming "Giant Erfles - $9.95," I'd love to see well-made Russian equivalents sold for 50 to 90 bucks. Right? And where else should they be advertised better that in TM?

Jesse Carroll
(address not available)

– I sure hope you're right, Jesse. A fresh supply of mil-surplus eyepieces would do telescope makers and amateur astronomers a lot of good. WWII surplus helped spur the growth of telescope making in the 50s and 60s.

HST, the Null Test, and Technological Arrogance: Three Views

Techno-Arrogance

Most telescope makers who have followed the *HST* saga have no doubt heard of the infamous null test that caused the figure error in the *HST*'s primary mirror. Many TMs have probably scratched their heads trying to understand how two concave mirrors can be used to test a primary mirror, but the two-mirror null test used for the *HST* primary is easy to understand when you trace its evolution from the same tests TMs use to make their own mirrors.

Let's start with the familiar Dall null test in which a small simple lens is placed between a pinhole and the mirror. The lens introduces spherical aberration equal to the paraboloid's aberration at the center of curvature, but with the opposite sign. The aberrations cancel and produce a null with the knife-edge test. The Dall null test is a tremendous improvement over the traditional zonal measurements most TMs make to check figure quality.

Although high-quality mirrors can be produced with the Dall null, the test has limitations when it is applied to large, fast primaries because it tests the mirror off the optical axis. The size of the null lens, and thus the degree and quality of compensation, is limited by the maximum allowable separation of the return beam from the primary and the pinhole due to the resultant astigmatism.

When the simple lens is placed on a line between the test apparatus and the optic under test, as it is in the Ross null test (described in *TM#39*), the mirror is tested axially and the arrangement allows for better compensation because the lens can be as large as is practical with no ill effects. The Ross null test is most suitable for mirrors in the size range TMs are most likely to make. When the aperture exceeds 24 inches and the focal ratio is faster than f/4, the Ross null test cannot compensate the mirror's aberration unless a lens of at least 6 inches in diameter is used. Perfect compensation would call for a Ross lens as large as the primary, but such a solution is hardly ideal or practical.

However, the optical equivalent of placing a large lens at the mirror can be achieved by using the Offner null test. The Offner test uses a simple lens compensator that is smaller than the lens used in the Ross setup, and the lens is used as a relay lens. The strength of this test is a field lens placed at the center of curvature of the primary. The field lens forms an image of the null lens onto the surface of the mirror, thereby achieving essentially perfect compensation. In other words, the Offner test is like having a full-aperture Ross lens.

Spaceborne telescopes require figures accurate to 1/100 wave RMS on large, fast mirrors. While in theory the Offner null test can be easily designed to accommodate such tight tolerances, difficulties are sometimes encountered in practice because of inhomogeneities in the glass used for the null lens. Typical variations in refractive index over the aperture of a null lens can easily introduce considerable aberration. Schott Glass Technologies, the world leader in optical glass, guarantees only 1/2-wave transmitted wavefront quality for its basic optical glass BK7, although top grades of glass are generally better.

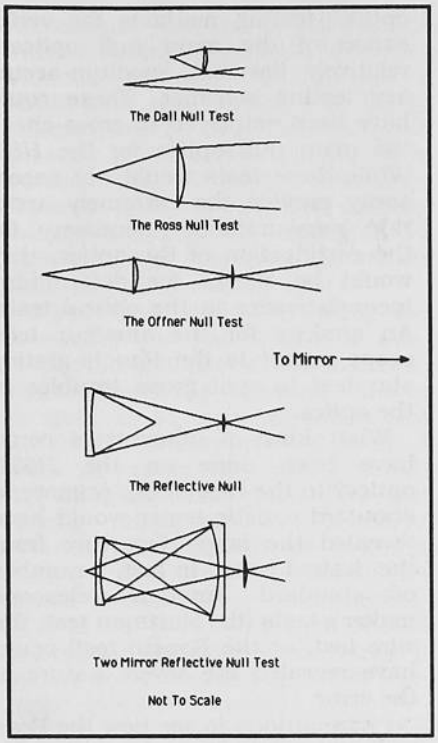
To avoid glass homogeneity problems, spherical mirrors, instead of lenses, are used as compensators. The surface accuracy of a mirror is easier to control than the internal quality of a lens blank. A single-mirror reflective null (combined with the appropriate field lens) is equivalent to the Offner null test. Because the field lens is at or very close to the center of curvature, the lens can be very small. Furthermore, it will have little effect on imaging, so the quality of the glass it is made from is not as critical.

However, unlike lens-based tests, the focus of the reflective null is inaccessible, and this presents a real problem for the optician when an interferometer is to be used in conjunction with the null arrangement. While a flat can be used to make the focus accessible, it is possible to use a second spherical mirror in a somewhat more complicated arrangement to not only make the focus accessible but also provide enough compensating power for primaries up to 3 meters in diameter and as fast as f/1.5. The two-mirror null was the type used during the final figuring of the HST primary.

It has been revealed recently that Perkin-Elmer technicians checked the mirror with another null system. After the mirror was declared finished, a refractive null system (presumably the Offner null) revealed 1/4-wave of spherical aberration. This test result was discounted, however, because of the "coarseness" of the refractive null (presumably the glass homogeneity problem) when compared to the lovingly crafted and ultra-precise reflective null system.

Telescope makers have learned a valuable lesson, at the expense of Perkin-Elmer technicians and NASA engineers, about applying null tests: cross-check your test methods. If you find discrepancies, don't fall victim to technological arrogance and automatically trust the fancy null setup. Human error is too insidious to ignore.

I myself pulled a *Hubble* in a very small way. In the Ross null article in *TM#39* I told of how I figured a



12.5-inch mirror to perfection with the Ross null test. But while I calculated and measured the spacings correctly, I inadvertently placed the lens backwards. The result was similar to the *HST* primary: an excellent but totally wrong figure.

Immediately after I decided the mirror's figure was fully cooked, I removed the null lens and tested the mirror by roughly measuring the difference in focus of the center and edge zones. To my surprise, the focus difference was six times greater than required. Luckily I didn't launch the mirror into space before I discovered my error.

The moral of the story is this: before you consider a mirror finished, check it with the simplest test at your disposal. Try either the standard Foucault test or, better yet, check it out on the stars before the mirror is aluminized. While such simple precautions may not reveal very minute defects, they will eliminate gross errors.

—Peter Ceravolo

Can It Be Fixed?

Fixing the *Hubble* telescope presents a challenge to the optics community. The cause of the error is now known, and there are several possible "fixes"—but none are attractive. The Hubble telescope is a Ritchey-Chretien type of design. This means that both the primary and secondary mirrors are hyperboloids. Although the radius of curvature of a parabolic mirror uniquely determines the mirror figure, there are an infinite number of different possible hyperboloids (each with a different eccentricity) for any given radius of curvature.

In the *Hubble* telescope design, both the primary and secondary mirrors are supposed to have particular hyperbolic eccentricities, in addition to their particular radii of curvature. The news media have often erroneously described the optics problem as being a curvature error on one of the mirrors. In fact, however, both mirrors have the correct radii of curvature and the correct spacing. Furthermore, both mirrors are essentially perfect hyperbolas. The problem is that the primary mirror was given the wrong hyperbola.

The departure of the actual primary mirror hyperbola from the desired hyperbola amounts to 6 to 7 waves of spherical aberration on the reflected wavefront. By going to best focus, instead of looking at the paraxial focus, these numbers can be reduced quite a bit. The wavefront error has been determined to be overcorrected spherical aberration. It turns out that undercorrection would have been much better for some of the possible "fixes" that will be described later.

The best estimate is that the wavefront error is about .5 waves root mean square for visible light. This is about seven times worse than what we would call a just barely diffraction-limited system. As a result, angular resolution is about 0.7 arcseconds (in visible light) instead of the predicted 0.1 arcseconds for a "perfect" telescope of this aperture.

The error was determined to be on the primary mirror and not on the secondary mirror because an error of this size on the secondary would result in a disturbance in the coma correction of the design that could easily be seen, while no such effect would occur if the error were on the primary mirror. In fact, what is seen is essentially a constant amount of spherical aberration that does not change with field angle—i.e., no coma.

Source of Error

The cause of the error in the primary mirror hyperbola is to be found in a special reflective null test, involving some auxiliary mirrors and a lens that was used to check the figure of the primary mirror from its center of curvature. The test was used repeatedly in the final stages of figuring the primary mirror. This null test was designed properly and its components were properly made. During the assembly of the test, however, certain procedural errors were made that resulted in the spacing between the mirrors being wrong. A small spacing error in the positioning of the null test components easily accounts for the error on the primary mirror.

It is important to realize that this unfortunate mistake is no reflection on the quality of the optical design of the telescope and its null test optics, nor on the superb surface figure on the primary mirror. An essentially perfect mirror was made—it's just that it is the wrong perfect hyperbola.

"Fix" for Problem

The simplest fix, conceptually, for the error is also the least desirable—namely, to replace the huge primary mirror with one having the correct hyperbolic surface. The backup mirror made by Kodak presumably has the correct surface figure. Swapping mirrors would require returning the whole telescope to Earth first. No one wants that.

A very simple idea that might seem to have merit is to change the separation between the primary and secondary mirrors by a small amount. It turns out to be possible to eliminate the 6 or 7 waves of spherical aberration by moving the secondary mirror by a fraction of an inch. Unfortunately, the high magnification of the secondary mirror would result in shifting the final image location by several feet. Since the various instruments (spectrographs, etc.) in the back of the telescope are fixed in a particular location, they could not accept such a large shift in the final image position.

A more complicated idea is to rethink the secondary mirror situation as follows: could a different secondary mirror (i.e., a secondary with a different position, radius, and figure) form a good image? The simplest thing would be to replace the secondary mirror with another one in the same position and with the same radius but a different hyperbola. This would leave the final image in the right position and would allow the spherical aberra-

tion to be fixed. However, the system would no longer be corrected for coma, which would be about three times worse than a classical Cassegrain design with the same first-order parameters. The diffraction-limited field size would be greatly reduced, but at least there would be a perfect image near the optical axis.

By shifting the position and radius of the secondary mirror as well, we could get back to a coma-corrected Ritchey-Chretien design. Suppose the secondary mirror is moved closer to the primary mirror by about 12 inches and its radius changed to keep the final image in the right place. If the secondary's hyperbola shape is then chosen to correct for the spherical aberration error in the primary mirror, a coma-corrected design will result as well. This change would require a 16-inch diameter secondary mirror, instead of the present 12-inch diameter, and would give the telescope a substantially faster focal ratio. It is unlikely that this change in the structure around the secondary mirror, baffles, etc., could be made with the telescope in space.

Another option involves placing a weakly curved pair of 12-inch diameter fused-silica lenses with zero net power right against the secondary mirror. Light would pass through this pair of lenses twice. Such lenses could be designed to give a final image corrected for spherical aberration and coma, with essentially no color effects. On-axis, such a design could be diffraction-limited over most of the transmission range of fused silica, from the deep ultraviolet through the near infrared. There are some color problems off-axis, but the monochromatic field size is quite large due to the excellent coma correction. This fix would not require any change to the present mirrors, but it may not be possible to place these corrector lenses in position against the secondary mirror while in space. No provision was made for easy access to the telescope components for such tinkering. Who would have thought that it might become necessary?

A completely different kind of fix is to do something down near the final image. A field group of lenses near the image is a fine place to correct astigmatism and coma but is a terrible place to correct spherical aberration. Such solutions tend to have strongly curved lenses and present a lot of problems reaching decent performance. Color correction is usually not good either. Correcting 6 to 7 waves of spherical aberration down near the image is just not the way to go.

A much better idea, and apparently the one with the best chance of being implemented, is to have a separate fix inside each of the different instruments that examine the telescope image. Most of these instruments, like the spectrographs, have internal optics that form an image of the primary mirror inside the instrument. At that location, a small aspheric plate or a small zero-power doublet lens could be used to fix the spherical aberration problem without introducing other aberrations. Aberration theory indicates that the ideal place to do such correction is at a pupil. Such a corrector lens would be quite small. It may have to be of moderate complexity in order to cover a very broad spectral range with good performance, but it is definitely a doable design task. The question then becomes how difficult it might be to install such corrector lenses in the instruments.

In summary, several "fixes" exist for the *Hubble* telescope problem, though none seem to be especially attractive. All involve compromises of one sort or another. Although it is doubtful that the *Hubble* primary mirror will turn up as part of someone's telescope at Stellafane or Riverside in the near future, the future of this mirror remains cloudy.

David Shafer
56 Drake Lane
Fairfield, CT 06430

Didn't Anyone Ask an Astronomer?

An error in the spacing between the elements in the null corrector used to make the tests caused the primary to be made to the wrong conic surface. This error is, in fact, a serious human error which should have never occurred. I know this probably sounds like "after the fact armchair quarterbacking," but the spacing between null elements can be set to wavelength tolerances, not millimeters. And considering the number of years spent in grinding, polishing and testing the *HST* optics, the null corrector should have been checked thoroughly many times over.

It would seem to me that whoever made something as expensive and labor-intensive as the *HST* optics would have used several backup optical testing methods for verification of the main null optics—relatively low-cost, medium-accuracy testing schemes. These could have been employed to cross-check the main null optics for the *HST*. While these tests would not necessarily provide the extremely accurate measurements necessary for the certification of the optics, they would be useful for determining inconsistencies in the optical tests. An analogy for the amateur telescope maker is the Ronchi-grating star test to spot gross troubles in the optics.

What kind of other tests could have been done on the *HST*'s optics? In the case of the primary, a standard caustic tester would have revealed the large departure from the desired conic. In fact, a number of standard amateur telescope maker's tests (the Hartman test, the wire test, or the Ronchi test) could have revealed the severe nature of the error.

I was curious to see how the Ross null test would have done with the *HST* primary. Not surprisingly, it produced a poor null due to the large diameter primary (2400mm) and the fast focal ratio (f/2.3). The best wavefront with the single lens Ross test was about 3.5 waves residual wavefront error. A doublet or triplet null lens would have brought the wavefront error to less than 1/10-wave and could have served as a cross-check for the main null optics.

Another interesting possibility would have been to diamond machine the convex surface of a high-index Ross null lens into an aspheric null lens. Suitable materials could be ZnS, ZnSe, or Cleartran (an optically clear ZnS). The use of this singlet as a go/no-go gauge to crosscheck the null optics would have been quite easy to implement. Such lenses are commonly used today for similar applications. The bottom line is this: for a few thousand dollars in materials, any one of several medium-quality optical testing schemes could have served to check for just the type of human error seen in the *HST* optics today. This would seem to be some pretty cheap insurance, considering the costs of the whole *HST*.

Regarding the lack of testing of the primary/secondary together, this is also quite disturbing. If I were on the commission looking into the *HST* optical problems, the first question I would ask is, "Has any ground-based observatory ever

successfully made a secondary without having it tested as a system with the primary?" The answer I would have gotten from professional astronomers is "NO." So then the question is, "How is it that we think we can make the world's best large diameter optics in the *HST* without testing them together, seeing as we have not been able to do so yet on other large observatory optics?"

When faced with fabricating the secondary for the 200-inch telescope, the opticians at Palomar constructed an array of "small" flats to be used in an autocollimation test as the secondary was figured. I know we can do some pretty incredible things optically these days, but mating large-diameter primary/secondary combinations without testing them together does not appear to have been done successfully in the past. Why then should anyone (or any agency) have tried it on the most demanding set of telescope optics ever made?

When the announcement of the *HST* optical problems first came out, I assumed the problem had to be with the secondary, because the primary should have been tested in so many different ways. Also, the secondary mirror has a magnification of 10.4 times, so its sensitivity to fabrication errors is likely to be very high. So I set up the *HST* nominal optical system on the computer and began to analyze some of the system characteristics. I tried to see how much the secondary had to depart from its nominal design to produce such results. By varying the asphericity of the secondary and its spacing from the primary, I found that a slightly weaker secondary (only one-half wave departure from the ideal secondary) spaced only 0.0055 inches further away from the primary (a change of only 0.003%) would produce the spherical aberration problems seen today in the *HST*. Clearly, a little bit of a problem with the secondary could go a long way in the system performance.

Next I assumed that the secondary would be tested with a Hindle sphere arrangement, not unlike many Cassegrain secondaries. The *HST* secondary is about 12 inches in diameter, so a relatively small Hindle sphere could be used for testing it. I set up a nominal Hindle sphere test on the computer and checked how sensitive the test system was to spacing errors; that is, how much spacing error between the Hindle sphere and secondary was needed to produce the half-wave secondary described in the last paragraph? The answer was 0.0075 inches, or about 0.02% change in spacing. While 0.02% spacing measurements are certainly not impossible to make, they are definitely demanding and require precise work and attention to details. The point is, however, that if the secondary were placed even a few thousandths of an inch off the desired position during the figuring stage, it would be figured to the wrong conic. And because it was never tested against the primary, only during actual use in space would the error be discovered.

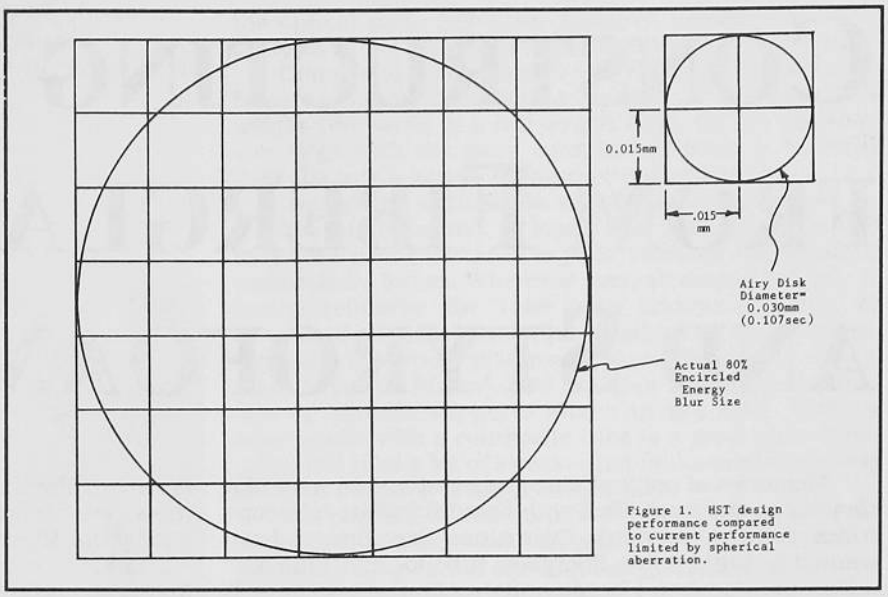


Figure 1. HST design performance compared to current performance limited by spherical aberration.

I think it bears repeating that the *HST* optics are the most demanding set of telescope optics ever attempted. As such, test requirements for these optics are equally demanding. Relatively simple cross-checking tests should have been used when figuring the primary. And certainly the primary and secondary should have been functionally tested together prior to completion. Even a sub-aperture flat one half the diameter of the primary would have been sufficient to catch the gross figure error seen today.

In know there will be those who criticize these statements because I am making them in hindsight. Believe me, I make enough optical mistakes every week to be sensitive to the reality of human error. Let me frame the question this way: Suppose that you were in charge of delivering the most expensive and most accurate telescope ever built by mankind. How would you guarantee the performance? By trusting only one null-test arrangement? By not testing the primary and secondary together in some fashion? I think you would insist on backup test methods.

The null tester alone has two mirrors and a lens; there are enough possibilities here alone to warrant a cautious approach. What if one of the constructional parameters of the null tester were set incorrectly—how would you ever know if you didn't have a confirming test or two? The key concept here is to expect some form of human error and to use several approaches to test for just such a condition.

Let me say in closing that this is not intended to attack or disparage anyone who worked on the *HST* program, and especially not the Perkin Elmer people (now Hughes), nor NASA. Certainly there are no better optical people in the world than those who worked on the *HST* optics. Very few of us are privy to the inner politics of large projects like the *HST* program and to the way decisions get made. For years now, I have been going to schools and other gatherings telling about the wonderful technology that has culminated in the *HST*. Every one of us as an ATM has probably spoken similar words to others, and it is our collective pride that gets bruised by such a flaw occurring in our hopes and dreams. In some way we will all learn a good lesson from this, hopefully without discouraging the next generation of scientists and engineers.

David E. Stoltzmann
368 N. Ninth Street
Bayport, MN 55003

Constructing Tubes from Fiberglass and Styrofoam

Memories of my first star parties at age 14 were of a clearing in the trees filled with beautiful white telescope tubes pointed skyward. Ever since that time, I have wanted to build a fine fiberglass tube for my "ultimate" telescope. So when I began construction of a 17.5-inch equatorial several years ago, I made my own tube.

There are several advantages of a tube over a box structure. Aside from aesthetics, a tube rotates easily, is stronger than a box, and is the ideal shape for a field stop. On the negative side, a tube is harder to make than a box. It is harder to get a professional-looking finish on a tube, and in Dobsonians, the tube is somewhat superfluous since a box is the simplest structure to use for mounting on the rocker box. Hence, the choice of a tube or a box comes down to personal preference. I chose a tube for its aesthetics and rotatability, and I decided to combine the tube with a Serrurier truss to make the telescope more portable.

The first choice I faced was whether to buy a tube or make it myself. The commercial tubes I had seen were thin (too flexible), were made of cheap materials, tended to crack with age, smelled of polyester resin, and had unsightly seams. They were also expensive.

But there were also problems with building a tube myself: fiberglass work is extremely time-consuming, it is difficult to get a professional finish, and doing the job doesn't really save you any money if you do things right and use better materials. But my desire to control the quality of the tube convinced me to make my own.

I made several tubes of increasing size and quality, roughly following the methods outlined so well by N. E. Howard in *The Standard Handbook For Telescope Making*. But Roger Sanders' excellent article on composite materials (*S&T*, December 1983 and January 1984) convinced me to take advantage of the new materials. This was reinforced by a superbly constructed tube made by Tom Fox and Dave Pitou for a 12.5-inch (*TM#33*, pages 36 and 37), which I saw at the 1988 Riverside TM conference. (Since then I have seen one other composite tube, made by Gary Grue and Tom Scott for their magnificent 24-inch scope, exhibited at the 1989 Riverside conference and mentioned in *TM#37*, page 42).

In constructing the tube for my 17.5-inch scope, I learned some things that might be of interest to TM readers. Many of these ideas apply not only to tubes but also to other fiberglassing projects for telescopes.

Structural Considerations

I made the mistake of making my early tubes out of pure fiberglass. The 1/8-inch-thick tubes were stiff and were unbelievably heavy. I could have reduced the weight greatly if I had stopped to think about why a tube is strong. (For an excellent discussion of telescope structures, see the articles by John Brooks, *S&T*, June 1976, and by Bill Albrecht, *S&T*, February and March 1989).

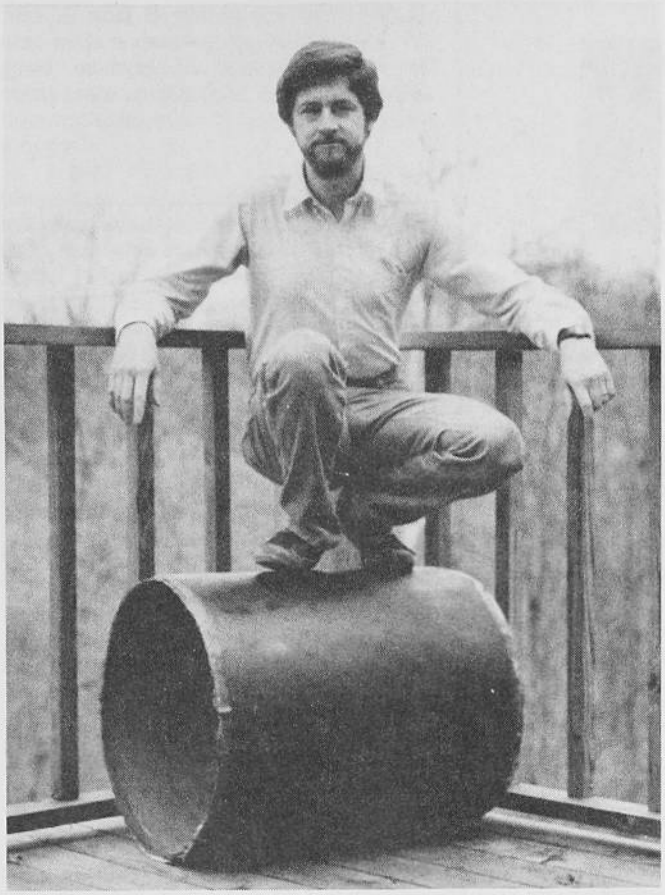
Imagine a very thick-walled tube composed of numerous infinitesimally thin concentric "tubelets" all in contact with each other. Since the resistance to tube flexure depends (among other things) on the fourth power of the diameter of the tubelet, one can see that the outer tubelet does the most work in resisting sag and the inner tubelet does the least. The inner tubelets still contribute to the overall stiffness, but decreasingly so as the diameter decreases. At the same time, the inner tubelets add weight according to the square of the diameter. Thus, the inner tubelets add more weight than strength and are an inefficient way to provide stiffness.

Consider a "typical" tube for a 17.5-inch telescope shown in the accompanying illustration. The top graph shows the moment of inertia, or the absolute stiffness of the tube, as the wall thickness increases. A "solid" tube, i.e., a solid round bar of fiberglass, provides the greatest moment of inertia. But note in the lower graph that the ratio of stiffness per unit weight is optimal for the thin tube and declines as the tube thickens.

This point is driven home by considering an example. A tube with an outside diameter of 20.2 inches, a wall thickness of 0.1 inches, and a length of 105 inches will weigh about 36 pounds, while a similar tube of 1-inch wall thickness would weigh some 178 pounds! This should discourage efforts to build excessively thick tubes, at least out of solid fibers.

On the other hand, the tube cannot be made too thin. Engineers say that a tube whose thickness is less than 2 percent of its diameter tends to buckle if placed under strong compressive forces. Hence, our 20.2-inch tube theoretically should be about 0.4 inches thick. In actual practice, we rarely run over telescope tubes with army tanks, so 0.2 inches is quite sufficient for this diameter.

The solution to minimizing fiber weight on the skin while still providing the minimum required thickness is to use composite construction techniques pioneered by the aviation industry. Glass fibers, which provide strength but also add weight and expense, are used for the thin outer shell. Inside, a layer of rigid foam (which is lightweight and cheap but adds little strength), helps the skin to resist buckling. Finally, an inner skin is added inside the foam to facilitate mounting the optics and to minimize crushing of the foam. The inner skin also adds more strength because it provides another "tubelet" that is in tension with the outer material. This "sandwich" construction thus optimizes the competing



Composite tubes are very strong and show little flexure under "typical use." This demonstration length of tube, shown prior to sanding, supports the full weight of the author. The Sonotube core that the composite tube was constructed on would have squashed flat.

objectives of rigidity, lightness, and expense.

Consider the example of the above 20.2-inch OD tube but with a 0.3-inch wall thickness. Such a tube made out of solid fiberglass would weigh about 110 pounds. For comparison, a composite sandwich tube would weigh only about 45 pounds. Thus, composite construction makes the difference between being able to lift a larger tube by yourself and needing to recruit several helpers every time you want to observe.

Expense is another reason to go with composite construction. The solid-fiber tube example, if constructed of fiberglass, would cost an outrageous $1,000, whereas a composite tube would cost less than $300. Exotic fibers such as graphite in the resin may raise the composite price, but the total expenditure would still be less than that for a solid fiberglass tube.

There are two additional, somewhat-less-important advantages of composite materials. First, they tend to dampen vibrations much better than rigid solids such as metals do. Foam is especially good in this regard. It might not be a bad idea to alternate metals with composites throughout your mount design in order to cut vibration. Second, composites are thermally inert for practical purposes. For example, the coefficient of thermal expansion for E glass is about one-third that of aluminum. This means that composites not only are dimensionally more stable with changes in air temperature, but also produce fewer thermal problems along the optical path. For these reasons, I make everything that lies in the light path out of composites, not metal.

Composite structures are so light that a Serrurier truss in combination with a short tube will save little weight compared to a full-length tube. So the only reason to go with the more complicated truss is to break the tube into sections to improve portability.

Designing with Foam and Fiber Composites

The big drawback of foam/fiber composites is that they have poor resistance to point stresses and to strong compressive forces. Wherever such stresses are likely to occur, reinforce the tube with additional cloth, or broaden the surface area that is subjected to the stress. Pay close attention to stresses in mounting the optics, truss supports (if any), and the area where the declination or altitude supports attach to the tube. Using a large cradle with a composite tube is a good idea. These tubes will take a lot of stress—just make sure the stress is distributed over a large surface area.

It is possible to make a tube very cheaply, but the old adage that "you get what you pay for" holds here. Unless you're building an old clunker, use good materials.

Cloth Type—Aircraft and boat construction industries have provided TMs with a wider range of materials than was available years ago. Now we have Kevlar, graphite, and two types of fiberglass (E and S glass).

Consider some of the characteristics of these materials as shown in the table. There are some critical tradeoffs between effectiveness and price. Fiberglass is cheap but is not as stiff as the exotic cloths; at the other extreme, graphite is much stiffer but is far more expensive. Kevlar is very resistant to hard impacts and stresses, but it is expensive and is harder to wet out with resin. Graphite is not very resistant to impacts, although it wets out nearly as well as fiberglass.

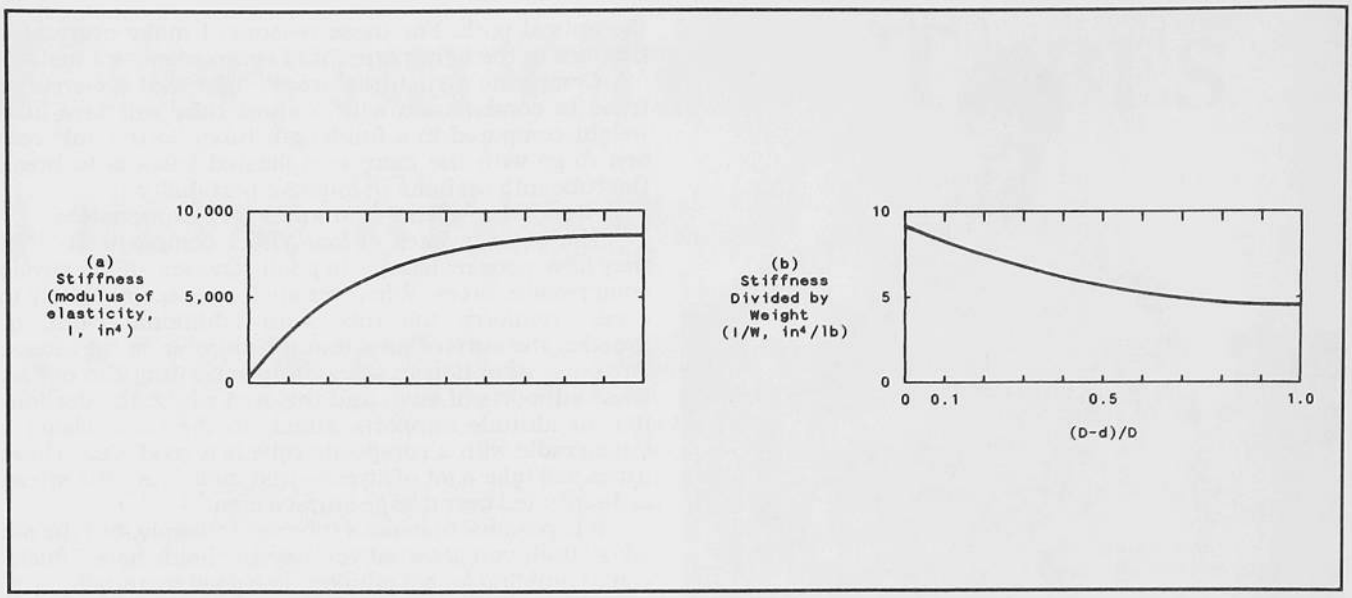
The best compromise is one that uses each material where it belongs. My solution was to use expensive graphite only on the critical outer shell of the foam, where it put strength exactly where it was needed while still minimizing the weight. I covered the graphite shell with a layer of E glass that protects my expensive, impact-sensitive graphite. This has an additional advantage in that when I sanded the exterior, I didn't remove any expensive graphite cloth, only fiberglass.

On the inside, I used several layers of E glass for moderate interior strength. I did not use S glass because of its disproportionately high cost compared to its stiffness. I did not use Kevlar because I could save weight by going straight to graphite.

I should note here that there is no need to rush out and use the exotic cloths. They are very expensive, and even if you have the money, there's something very pleasing about making an inexpensive scope that works well. Furthermore, consider that the major advantage of exotic fibers is to give great strength while saving weight. If you're making a small scope or a short tube for a Serrurier truss system, the savings in weight is not that important.

If you're making a long tube, however, the weight saved by using graphite cloth could keep your friends from referring to your overloaded mount as "Ol' Jello." Plus you'll have the distinct advantage of not requiring a hydraulic lift to move the tube.

Cloth Weight—Cloth weight varies from 2 to over 40 ounces per square yard. A somewhat stronger structure is probably made by using many layers of light cloth as opposed to a few layers of heavy cloth. But since cloth price goes only partly by weight, this is a very expensive way to do things. Instead, the weight



Stiffness (a) and stiffness normalized to weight (b) of a tube for a 17.5-inch telescope. The outer shell contributes the most toward stiffness, while inner layers are weaker and add more height. D is the outer diameter and d is the inner diameter.

you choose should probably depend on workability. I like cloth that is around 10 ounces in weight. Lighter cloth tends to move too easily, creating a fiberglasser's nightmare—air bubbles. Heavier cloth is harder to wet out and creates more work when it's time to fill in the weave for a finished appearance.

Matte Versus Cloth—Fiberglass and other fibers come in two forms, matte and cloth. Matte consists of short strands oriented in random directions and pressed together, like felt. Cloth has long, continuous strands oriented in perpendicular directions and woven together. Cloth is much stronger than matte and is easily the best choice for your tube.

Cloth Weave—There is yet another factor to consider: the weave of the cloth. With glass and Kevlar, you can obtain both plain and crow-foot weaves (see the accompanying illustrations) as well as others. Plain weave gives the best strength. There is also a choice of unidirectional or bidirectional cloth; always use a bidirectional weave when using E glass.

Graphite also comes in unidirectional and bidirectional weaves. Unidirectional cloth has all the graphite fibers parallel to the axis of the cloth roll; the fibers are lightly to heavily woven together with perpendicular glass or Kevlar strands. This cloth is strong in the direction of the graphite strands and is very weak perpendicular to them. True bidirectional cloth has graphite strands running in both directions, giving equal strength in all directions. Bidirectional cloth is always the best choice for long tubes, where radial strength and longitudinal flexure are both key concerns. There is also available a type of cloth which technically is unidirectional but has a tight weave of E glass perpendicular to the graphite fibers. This is an acceptable substitute for bidirectional cloth for shorter tubes.

Resins—There are two basic types of resins for fiberglassing: polyester and epoxy. Epoxy gives a better bond and a harder finish. Epoxy also stinks less than polyester (even an older polyester tube stinks slightly when warmed). Epoxy's disadvantages are that it costs three times as much, its setup time is 45 minutes and is not controllable, and its strength is dependent on the right resin-to-hardener ratio. However, epoxy resin is easily my first choice in telescope work. I like to look through a telescope, not smell it.

Foam—It is always possible to use Sonotube or similar cardboard tube instead of foam, but cardboard is heavier and can warp over the long haul in humid environments. I prefer foam. So long as you stick to good epoxy resin, you can use Styrofoam (a Dow Chemical product), urethane, urethane-polyester, or PVC. The choice will depend on availability, available size, and price. But first check on the maximum useable temperature of the material you plan to use. Foams tend to deform between 160° and 250° F; get a foam with as high a threshold temperature as possible. It's hot under that tarp in the noonday sun.

Order a thickness which is over 1% of the diameter of your planned tube. Foam that is 1/4-inch thick is best for tubes up to about 20 inches in diameter, but I would probably go to a 1/2-inch foam for larger sizes. Hopefully your tube won't be subjected to crushing forces, so you may be able to relax this rule a bit.

You may not be able to get foam in the large sheet sizes needed for your tube. But it is acceptable to join two or three pieces together, since most of the strength comes from the fiber, not the foam. Nevertheless, minimize the number of joints. Sheets of foam should be joined with slurry, as explained later.

If for some reason you use polyester resin, be advised that certain foams such as Styrofoam are destroyed by polyester. Epoxy can be used with any type of foam.

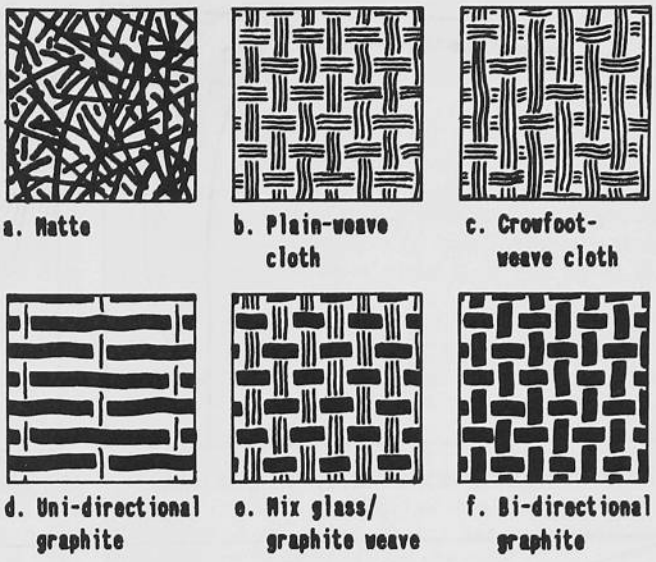
Suppliers—Fiberglass can be located in most reasonably sized cities. The phone book is your best source. Prices will vary a bit, so once you know the dimensions, weight, and weave of the cloth you want, it pays to shop around Aircraft builders would have an easier time of it, but I had a hard time locating sources of small quantities of graphite. Hitco's woven structures division (213/537-8210) sometimes has remnants at a good price. Aircraft Spruce and Specialty (P.O. Box 424, Fullerton, CA 92632; (714/870-7551) also has a good supply of graphite, as well as Kevlar

and E and S glass. Aircraft Spruce also sells a catalog for $10 which is a good source of information about composite materials and construction techniques. I recommend buying a copy.

I had difficulty locating companies which could give me some hard information about their foams. Few of the vendors I contacted had any idea about what they were selling. One man told me he had genuine Styrofoam, but when I arrived, all he had was useless cooler chest liner. I ended up buying urethane/pohyester from Aircraft Spruce. Aircraft Spruce also has a good selection of resins. I like their Safe-T-Poxy II for the exotic fibers. It wets out quite well on graphite and glass.

Construction Tips

Ordering the Materials—You will probably wonder how much cloth will be enough for your tube. My base tube for the 17.5-incher ended up being extremely stiff, so I'll give you the construction details for it and you can alter them as you see fit. The inner diameter is 20.4 inches, the thickness 0.33 inches, and the length 24 inches. I used two wraps of 9-ounce E glass cloth for the inner shell. The foam was 1/4-inch-thick urethane/polyester foam with a density of 4.5 ounces per cubic foot. The outer shell has five wraps of 11 ounce graphite, plain weave, with graphite fibers running around the circumference of the tube and E glass fibers running along its length. Outside the graphite I used two wraps of 6-ounce E glass cloth, which were partly removed by sanding. In all cases I used uncut runs of cloth. The final weight of the tube, sanded, is 10 pounds. The tube compresses less than 1/8 inch under a 100-pound weight; I have not measured its sag. The total cost of materials was about $280 (75% of which was in the graphite).



Types of weave in glass and exotic cloths. The weakest weaves are matte and uni-directional; the best are plain-weave, bi-directional cloth.

Comparison of Properties of Applicable Cloths

Material	Stiffness	Toughness	Density	Cost
E Glass*	1.0	fair	1.0	1.0
S Glass	1.2	good	1.0	1.8
Kevlar	2.5	excellent	0.5	4.5
Graphite/carbon	5.5	poor	0.7	9.3

* standard fiberglass

Figures are normalized to those of E-glass. Cost is based on a survey I did in 1989; it is cost per square foot normalized to E-glass, based upon price quotes for 6-ounce cloth in 42-inch-wide rolls. Market prices may vary depending on supplier, dimensions, etc. For the sake of comparison, E glass runs about 30¢ to 50¢ per square foot.

Since graphite is so expensive, you might want to use fewer wraps of it on your tube. My guess is that you will want at least two or three wraps of bidirectional graphite supplemented by several wraps of E glass. But due to the variety of available materials, it is very hard to determine in advance such parameters as tube sag. So I recommend using as much graphite as you can afford, especially for long and large tubes.

I used about half a gallon of resin on my tube. I recommend ordering a bit more than you think you'll need, because you won't always use all of a resin batch before it sets up.

Here is my recommended supplies list:

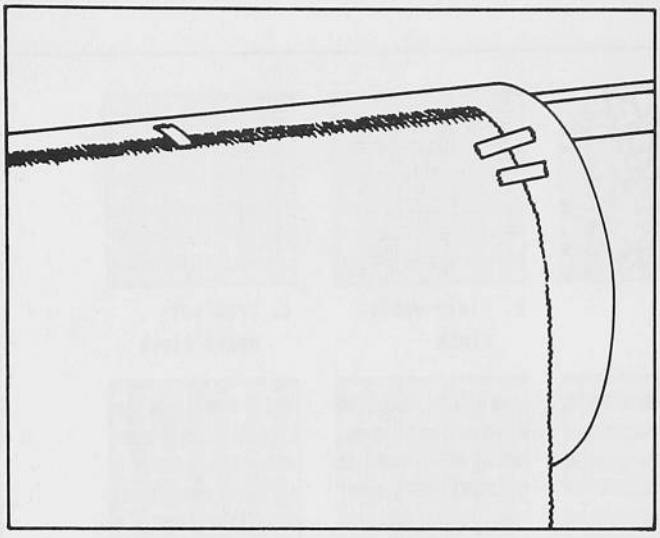
- Bidirectional graphite cloth, about 10-oz. weight
- Plain-weave E-glass cloth, about 10-oz. weight
- (optional) 6 oz. plain-weave E-glass for outer layer
- 1 to 2 gallons Safety-Poxy II resin and hardener
- Sonotube mold, preferably 0.25-inch wall thickness
- Fast-dry spray varnish
- Mold release liquid
- Two or three 3-inch stiff paint brushes
- Several pairs of cheap latex gloves
- Several clean coffee cans or plastic tubs
- Spatulas for stirring
- A scale accurate to 1 oz. of weight, or a way of accurately determining volume
- 1/4- or 1/2-inch-thick PVC rigid foam
- Sharp scissors and a sharp utility knife
- Lots of paper towels
- Duct tape and several rolls of drafting tape
- Acetone or similar thinner

and finally—

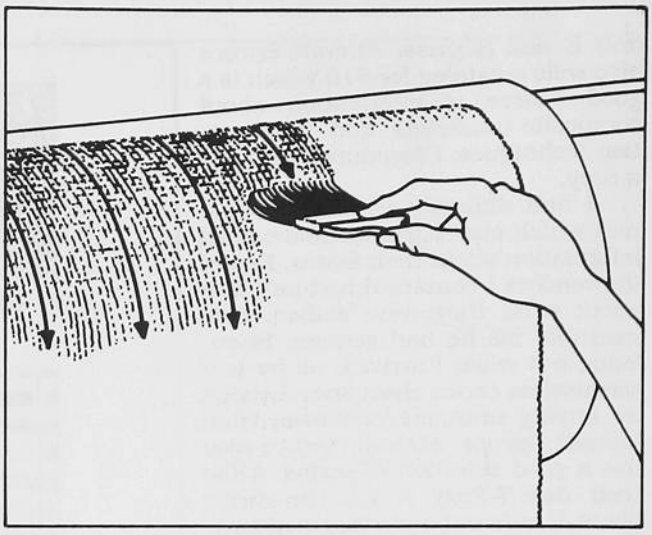
- Safety apparel as indicated in this article.

The Mold—The first thing you will need is the mold. Sonotube or similar cardboard tube is a nearly ideal mold. You can buy one of these for under $20 at a concrete construction supply house. Ask first if they'd like to get rid of a cut-off; they might give it to you for free. But check the tube for warpage or damage.

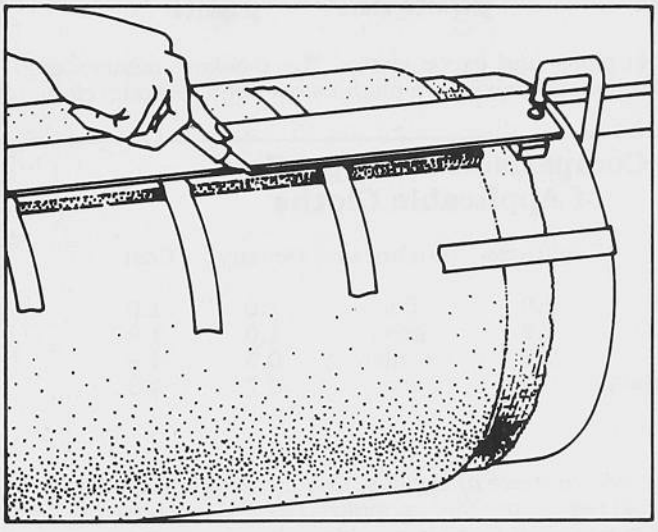
The outside diameter of the Sonotube should equal the inside diameter of your desired tube. This can be



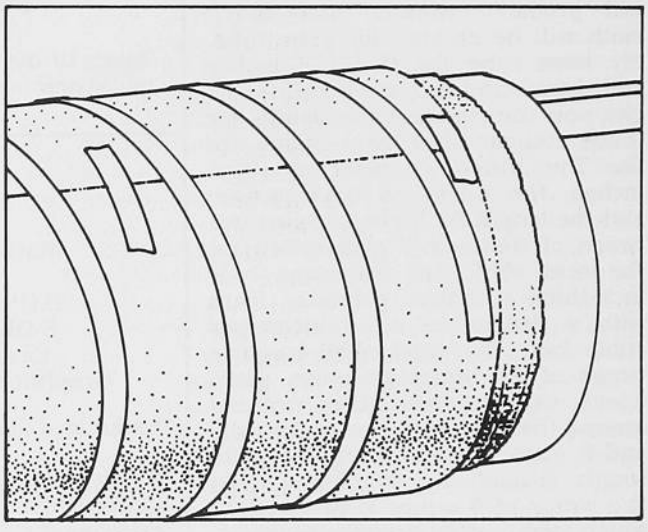
1.) Attach the fiberglass with a narrow strip of resin.



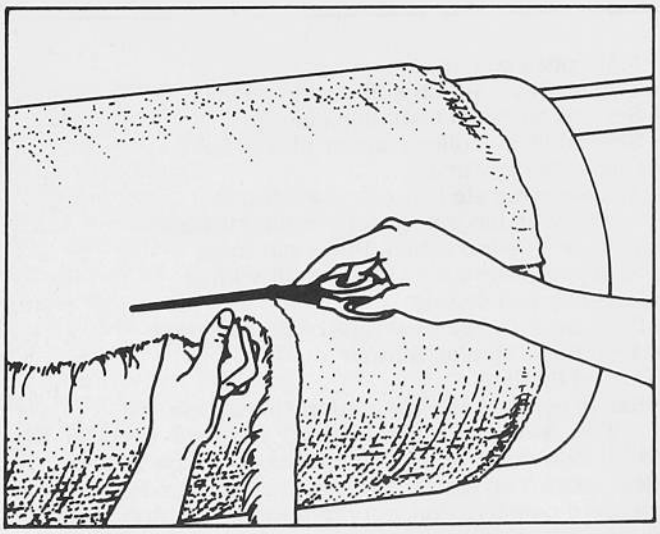
2.) Always brush resin in the same direction.



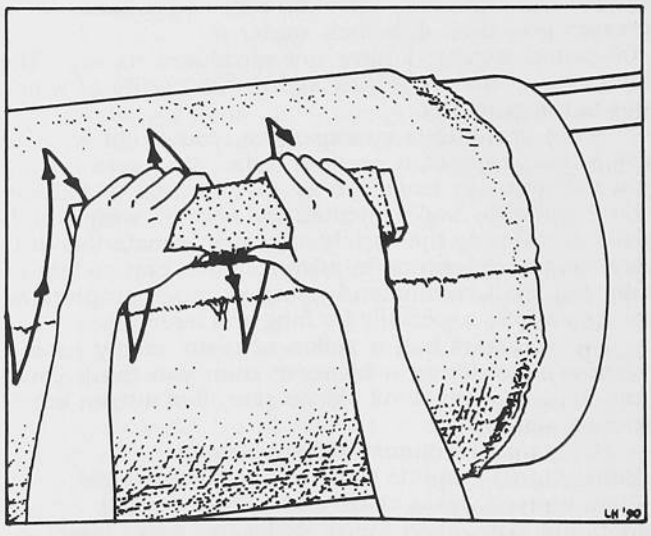
3.) Temporarily attach the foam and cut along overlap.



4.) Paint foam and tube with slurry; wrap it tightly.



5.) Cut the ends of cloth to avoid bulging at overlap.



6.) Sand the surface radially with smooth strokes.

Key Steps in Composite Tube Construction

trickier than it sounds because most Sonotube comes in 2-inch diameter increments (i.e., 16-, 18-, 20-, 22-inch). Because Sonotube diameters are specified by their inside diameter, add twice the thickness to get the outside diameter (which will be the inside diameter of your finished tube). Try to get the thicker tubes rather than the "lite wall" 0.175-inch-thick tubes. This will provide a more rigid mold and will resist mold sag when you apply the heavy fibers and resin. Get a tube about 12 inches longer than the tube you want.

Unless you can get a tube with a wax coating on the outside, you will need to coat the exterior of the tube to prevent the resin from sticking to it. I give the cardboard mold several good coats of spray varnish. I use the fast-dry type to prevent the cardboard from warping.

After the varnish is dry, I apply several coats of a good mold release compound. This step is indispensable because removing the finished tube from the mold will be hard enough because of shrinkage during catalysis of the resins. It is possible to use a sheet of plastic over the mold as well, but mold release compound works well enough. You may want to cover the cardboard seams with adhesive tape before treating it with varnish to eliminate a spiral band of resin on the inside of your final tube.

Setup—You will want to work on a warm day (preferably 70° to 85° F) with good ventilation, in the shade, and away from flying dust and debris. Prior to mixing your resin, get all your materials set up completely. I have available at least two 2- or 3-inch brushes, plastic gloves, three or more large coffee cans, and some throwaway measuring cups. Clean plastic butter tubs work well.

To support the work, I run a 2x4 through the mold and prop it up at about waist level on two stable stands. I run a piece of conduit through the center of the rolled cloth and rig up a simple way of turning it as I unroll the cloth. Be careful to keep the cloth clean, or your resin bond will suffer.

The Inner Shell—Carefully weigh or obtain the proper volumes of resin and hardener. Follow instructions with the resin to the letter—the resin strength is critically dependent on the right proportions. When everything else is ready to go, combine resin and hardener. Stir thoroughly but slowly, minimizing the amount of air you get into the mixture. I usually spend at least one minute to get a homogeneous mix.

To start the work, I mix up a tiny bit of resin and run a 1-inch strip down the length of the tube. I pull my cloth up and over the side of the tube facing me, and lay its edge down along the resin strip. I let this cure so that I start from a point where I know my cloth is not going to move. Sometimes it helps to hold the cloth in place with adhesive tape until the resin strip has cured. Work in the center of the cardboard tube, leaving 6 inches of both ends alone. This avoids irregularities in tube roundness found at the ends where it was cut and assists in turning the tube as you work.

After an hour or two, when the resin strip is hard, I mix up a good batch of resin. After working awhile, you will find out how much resin you can use before it starts to set up. I work rather slowly, so I use about 1 pint of resin in each batch. Incidentally, when I'm working I measure everything in metric units to avoid the senseless confusion of English units.

I start by painting a 4-inch swath at the start of the glass cloth, all the way down the length of the tube. To do this, I start at one end of the tube, working my brush from the 1-inch starting strip down the circumference of the tube. I then raise the brush and repeat with a new stroke an inch or so down the tube. This means the cloth is always pulled in one direction, toward me and down. Pulling tends to stretch the cloth tightly around the tube, minimizing problems with air bubbles.

When I finish with the first 4-inch swath, I start another 4-inch swath, rotating the mold up and away from me. I keep an eye on the clock to see when the resin will set up (usually about 45 minutes). I quit at 45 minutes or when the resin starts to thicken and get slightly globby. My brush gets an immediate cleaning in acetone; then I wash it in water and dry it so that no acetone remains in it to weaken the resin in my next work session.

Because resin does not add strength to the tube and serves only as a bonding agent, I try to use as little of it as possible. I like to leave the weave of the cloth exposed, while still making sure that every strand of the cloth is saturated. Unsaturated strands will be white in the case of fiberglass. It's best to use the pressure of the brush rather than an excess of resin to wet the cloth. If you do things just right, 1 pound of 9-ounce cloth will require 2 to 4 pounds of resin. If you use too much resin, your tube will be heavier but no stronger.

As you are working, beware of air bubbles. These are seen as lighter bubbles in the darker wetted-out fibers. Eliminate bubbles of over 1/8-inch diameter by brushing over them or stabbing them with the end of the brush. Pinpoint bubbles are no problem and are an inevitable result of the catalysis process. Watch for drips, especially on the underside of the tube. I closely examine each 4-inch swath for drips, excess resin, air bubbles, and unsaturated fibers before I move on to the next.

There is no need to cut your cloth in short segments, and indeed this will weaken your final structure. If I am laying up five layers, I do it using one continuous run of cloth. But I will usually pause with each complete rotation of the mold to let things set up before proceeding. This keeps the underlying cloth layers from moving against each other, which would produce air bubbles.

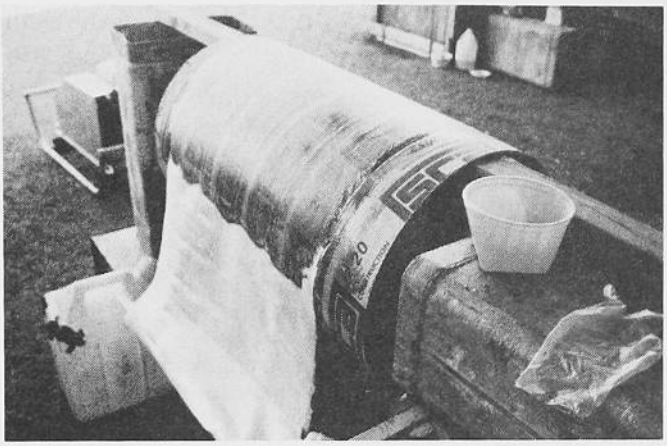
Don't fuss too much with getting nice, even, straight edges on the fiberglass tube. You can cut them off evenly later on.

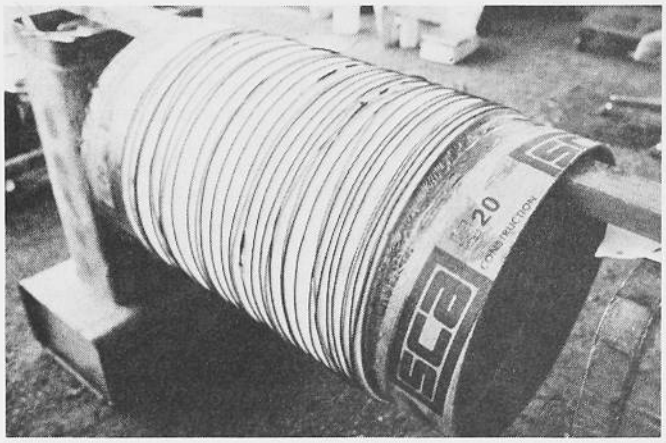
At the end of any run of cloth, do not allow the end of the cloth to overlap the beginning part. Instead, cut the end so that it lies over the beginning edge. This will help you make a rounder tube.

Attaching the Foam—After the first glass layer has cured a few days (longer if the weather is cold), find the circumference and cut a length of 1/4-inch-thick foam about 2 inches larger than the circumference. Wrap the foam very tightly around the tube; it should overlap itself by the extra 2 inches. Secure the foam with duct tape. Tape the edges as well as the overlap area. Check again that the foam is very tight everywhere against the tube. Using a straight steel ruler, cut down the middle of the overlap with a sharp blade to make a custom-fitted foam piece. Avoid cutting all the way through the foam so that you don't cut into the fiberglass; instead, remove the foam and finish the job on a table. When you are done, the ends should just butt against one another when the foam is wrapped around the tube.

If your tube is small or the foam is thick, you may have trouble bending the foam around the tube. Try heating the foam (up to about 150° F) if you need better pliability.

Mix up a slurry of epoxy and glass bubbles (roughly in a 1:1 proportion). Slurry helps the cloth bond better to the foam. But be careful: glass bubbles





Top: Starting layup for the inner shell; a concrete-form tube serves as the mold for the composite tube. Below: Around the inner shell of fiberglass you next wrap a layer of foam. The picture shows the foam layer after it was successfully wrapped and tied with wire.

become airborne and can irritate your lungs and eyes. Wear a respirator when you mix them.

Coat the tube with a thick but not quite drippy layer of the slurry. Coat the foam also. Wrap the foam around the tube; pull and stretch until the edges butt perfectly and the foam is on straight.

When I was doing the tube for my 17.5-incher the whole project nearly got away from me. My friend Gary Hall stepped in just in time to keep the semi-rigid foam from springing off the tube onto my face. My point is this: plan on having someone help you do this. It's amazingly awkward.

Tie the foam down with drafting tape, duct tape, or a long rope. I used 14-gauge insulated wire only because that's what I had available at the time. Check to make sure that the foam is very tight around the mold; otherwise you'll end up with an out-of-round tube. Be sure you secure all parts of the foam so that you don't get local bulges. Use more and tighter wrapping than you first think is needed. Let this set up for a week. You might look for drips during the first few hours. It's easier to wipe them up now than to sand them off later.

When the week is up, untie the beast and see what the damage is. Usually there will be some drips, holes to fill, etc. Take care of these before going any further.

The Outer Shell—I recommend proceeding directly with the graphite over the foam. Figure out the length you'll need for the number of wraps you want. Cut the proper length plus a spare inch or two. If you are using a mixed glass/graphite weave, be sure you have the graphite strands running around the tube, not parallel to its axis. Don't breathe the fine graphite strands that you've cut: they may be carcinogenic. Wear a mask.

Mix a pot of resin and glass bubble slurry and thinly cover the outside of the foam. Attach the end of the graphite roll and work slowly in 4-inch swaths as before, using a minimum of slurry. The cloth will be a little harder to wet than the glass, and it will be harder to actually see how well you are doing. But it's not too hard.

When you're done with one wrap, quit. Slurry does not do a good job of bonding layers of cloth to one another. Let the slurry set up for several hours (preferably) a day, then mix up a standard resin batch. Wet out one wrap at a time until your measured roll of cloth runs out. Be sure to cut the end of the roll so that it lies directly over the beginning edge of the roll, avoiding an overlap bulge.

Let the graphite layer set up for a day. Then proceed with your outer layer of E glass. I recommend at least two layers in case you sand through the first layer later on. Lighter weight cloth (say, 6-ounce weight) will make it easier to fill in the weave when sanding.

Removing the Mold—After the tube cures for a week or so, you can remove the mold. If you did a good job with the varnish and mold release, separating the tube from the mold will be only moderately painful. If you did a lousy job, you now have either a heavy cardboard-plus-composite tube or one terribly expensive sewer pipe.

To remove the mold, you peel the spiral cardboard from the inside of the tube. This is easier to do when the cardboard is wet. Peel off the inner wax coating and dump the tube in the bathtub or swimming pool. I can't begin to describe to you the reaction my wife had when she saw me bathing a telescope tube in our bathtub. She went away muttering. When she returned later to see the entire bathroom filled with wet cardboard peelings, it was time for some serious negotiating. Somehow grinding a big mirror is marginally acceptable to wives, but bathing telescope tubes is too much. I imagine husbands of female TMs feel the same way.

Sanding—After the tube has cured for a week or two, you are ready to sand it down. I have tried to use a power sander, but it just doesn't work for me on a tube. It creates flat spots and it gums up due to the high speed. I found that the best method is to use a sanding block and work by hand. I start with #60 paper and work my way to finer papers. I typically sand through the outer layer of glass before I have the smoothness I want. Be careful not to sand too much and start wiping out the graphite!

A word of caution: use a respirator mask over your eyes, nose, and mouth whenever sanding. The dust is very hazardous.

On the outside, I make steady long strokes around the tube, not along its length. This gives the best roundness. I check for high or low spots and tube bowing with a long metal straight-edge.

On the inside, I try to do only a very rough sanding—just enough to get the cardboard or fiberglass burrs off. By leaving the weave of the inner layer exposed, you can reduce the skylight bounce onto the mirror by a considerable amount. I also sand around the tube, not up and down its axis, in order to make the sanding grooves perpendicular to the incoming light. If the interior is too smooth, as it probably will be, you might consider laying in a final piece of 2- to 6-ounce E glass

cloth just to expose a reflection-deadening weave.

Some TMs feel no compulsion to finish their tubes smooth. Tom Fox and Dave Pitou's 12.5-inch scope has the cloth weave exposed and yet it is a beautiful scope. So suit yourself.

Filling—After sanding, the remaining minor cloth texture on the tube can be filled in with a uniform, light coat of resin or by the methods outlined by Sanders in his articles. I prefer resin, since it is simpler and uses no polyester-based filler. But the final resin coat does tend to gum up sandpaper in the final sanding.

When I'm done, I try to heat the tube to about 180° F to stabilize the epoxy resin. This is easy if you live in Arizona (as I did until recently). Just put black plastic trash bags over the tube and set it in the sun some hot summer day—it will get plenty hot. You can even fry chile rellenos on it. In other climates, Sanders' suggestion of a dry sauna should work fine for the tube, although the chile rellenos will be mushy.

Cutting—When the tube is sanded, the ends will still be irregular. Take a sheet of butcher paper and wrap it very tightly around the tube, being sure the edges meet perfectly (talc powder may help you get a snugger fit). This gives you the cutting line which is perpendicular to the tube axis. Mark the tube and cut with a bench saw or whatever you have available. A fine blade is best to avoid taking out chunks of the foam. Fill and sand the ends as needed. Don't leave foam exposed, but coat lightly with resin and sand smooth.

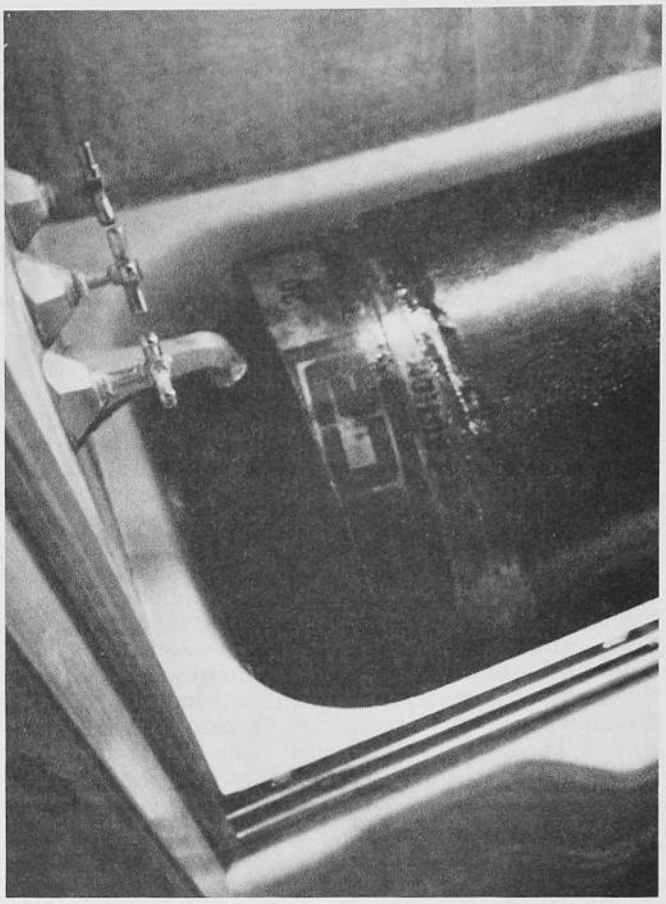
Painting—All resins deteriorate in the sun's ultraviolet rays, so painting is essential. Use flat black for the interior and whatever color you wish for the exterior. You might wish to consider Robert Cox's statements about tube color and thermal effects (*TM#26*, pages 40 to 45) before picking the traditional white.

The best paint for fiberglass products is epoxy paint. A two-part paint kit will adhere better than a one-part spray, but both are adequate for the task. I have found only limited selections of color in epoxy, and have rarely seen true flat black, so it may take some shopping around. Large hobby stores may have some at a premium price if your paint stores don't carry them. Buy a little extra for any touchup work years from now. One alternative to epoxy is to talk a friendly auto-painting shop into spray painting your tube the next time they do a car in the color you like. It doesn't hurt to ask.

Mounting Tips—It is worth repeating that you should avoid point stresses on the tube when mounting the optics, truss poles, cradle, etc. The mounting of the primary mirror may cause the most trouble. A good solution is to buy a roll of 2-inch wide graphite and lay up a layer or two of the inside of the tube where you will mount the mirror. Then cut some 2-inch-wide by 1/4-inch-thick aluminum angle into three brackets. Drill and tap the brackets for mounting to the tube and to the cell. Rough-sand the surfaces which will abut the tube, and epoxy and bolt the brackets to the tube at the reinforced ring. This will distribute the stresses over a broad surface area. Similar approaches may be taken to mounting the secondary.

Truss poles are best attached to the tube's cradle. If you must attach the poles directly to the tube (as I did for my rotating tube), be sure the mounts have a large contact area against the tube.

You can drill and tap composites, but always attach hardware with nuts which press large washers against the tube. Epoxying everything together adds additional security.



A soak in the bathtub helps you to peel away the cardboard mold from the inside of the finished tube. But watch out—your spouse may take exception to your telescope-making activities when they spread beyond the basement and garage!

Other Composite Projects—Because composite materials save weight, they are ideal for other telescope parts, especially those that are located above the main load-carrying bearing. Composites are useful for the tube cradle, fork arms, rocker boxes, etc. A few wraps of graphite over an appropriate cardboard tube makes a great diagonal mount tube. Graphite, wetted out and pressed between pieces of thick window glass, makes great spider vanes which are thermally inert and are at least as strong as an equivalent thickness of aluminum. You can even make your own mold forms from wood or dental cement to form complex shapes. The possibilities are endless.

Incidentally, if you are using graphite in your mount, bear in mind that this material is electrically conductive. So plan ahead when mounting your electronics.

Conclusions

There is no way to justify making a tube yourself unless you want high quality. After all, composite tubes are not even available commercially. Tube making is a long, tedious, and rather expensive process. But in the end you will have an excellent piece of workmanship that will make a beautiful and rigid housing for your optics.

Larry Hughes
1016 Crest View Court
Kingston Springs, TN 37082

Building a Yoke-Mounted Reflector for a Hinged-Roof Observatory

Twenty years ago, back in my early teens, I purchased my first respectable scope – a modest 6-inch reflector (a Criterion RV-6). For nearly a decade, this scope served well to introduce me, through the eyepiece, to the splendors of the night sky (and on occasion still does).

Since I also had an interest in photography, the 6-inch was later modified to do astrophotography – though it was in no way intended for such work. The drive, while fine for visual use, was something of a nightmare while taking photos. Removing my eye from the guide eyepiece for more than a second invited a 50/50 chance of an uncorrected tracking error and a ruined photograph. The scope also lacked the solid mount needed in astrophotography and shook in the slightest breeze. Still, over several years time I was able to acquire a couple hundred good photos—mainly the result of severe perseverance (sort of brute-force astrophotography).

As with many amateurs, I gradually began to consider the merits of someday having a larger scope. Ideally, it would also be one designed optimally for astrophotography. Based on my experience with the 6-inch, I made mental notes on what it would have to be like.

It had to have an exceptionally smooth drive. The mounting had to be rock (I mean ROCK!) steady and be able to carry some fairly hefty equipment such as piggybacked wide field scopes for photography—along with the regular camera at prime focus. And, of course, I would require a scope of sufficient aperture in order to get down deep into the sky and a focal length long enough to record the detail in galaxies and nebula that I wanted in my photos.

Ideally, the scope would also be permanently mounted. I had numbed my fingers too many times on winter nights fooling with Allen wrenches that often seemed to fall in the snow while I was polar aligning (which in itself wasted valuable observing time).

Much of the above wish list is pretty common among amateurs. But for me, there was an additional twist that had to be considered.

I was born and raised in the Adirondack Mountains of New York State, an area where, in places, the skies are quite dark (when they are clear). When I decided to make this scope, I resided just outside Albany, NY, where light pollution is rather severe (quite detrimental to deep-sky work). In order to do my photography with the 6-inch, I often took trips to the Adirondacks and visited my parents, but this necessitated a drive of 120 miles. Worthwhile deep-sky work from my rented house in Albany was out of the question. If I were to build a larger scope to do photographic work, the ideal place to put it would be in the Adirondacks, although this would be something other than the ideal walk out to the backyard to observe. I frequently made trips to the mountains to ski, hike, and fish, but was it really practical to have an observatory so far away? I debated this for several years. Then reality finally set in—I could continue to think about it, or DO IT!!

I decided that the scope (and an observatory to house it) would be built, assembled, and tested in Albany, then be disassembled and trucked to the mountains, to be reassembled and used there. The complications imposed by the move would have to be considered throughout the design, but I would not compromise the requirements of a superior telescope.

Take 1: the Inital Idea

Plans were drawn up during the winter of 1983-84. The scope would be a 14.5-inch f/6 Newtonian on a large German equatorial pipe mount. It would sit on a concrete pier—probably in a roll-off-roof observatory. The aperture of 14.5 inches was chosen, as I greatly admired the work of Evered Kreimer who used a 12.5-inch f/7 Newtonian with a cold camera. I figured that since I did not own a cold camera (at the time), I would go the next step up in aperture, and a step down to a slightly faster photographic speed—f/6. The focal ratio of f/6 would also be close to the fastest I could employ and not have coma show at the edges of my 35mm film frames. It would also give a good even illumination across the frame.

The pipe mount design was chosen as I had no access to sophisticated machine tools, and it seemed to be the easiest way to construct a solid mounting (which, at the time, I somewhat analogized as meaning steel). The design was taken from a book on telescope making which showed plans for a scope of 12-inch aperture on such a pipe mount. As for the difference in the scope size, I figured I would just scale up the mounting (roughly translated that meant using larger pipe). But before the mounting would be built, the tube assembly had to be made.

Making the Tube

Originally I thought there had to be something out there that would serve properly as a tube. It would have to be roughly 16 inches in inside diameter, 8 feet long, and very stiff (I planned on using a guidescope for photography, which would not allow for differential flexure between the main scope and guidescope). My search for this ideal ready-made tube came to naught. (I was, and still am, partial to a true closed tube as it minimizes stray light, allows for easy mounting of accessories such as a guidescope and, especially, keeps dew, frost, and dust off the mirrors).

About this time, much was being published about the use of fiberglass for the making of telescope parts.

The observatory shown fully opened and ready for operation. Note that the sky is unobstructed excepting for a small area below the pole. The lower walls form a handy shelf at elbow height all around the telescope.

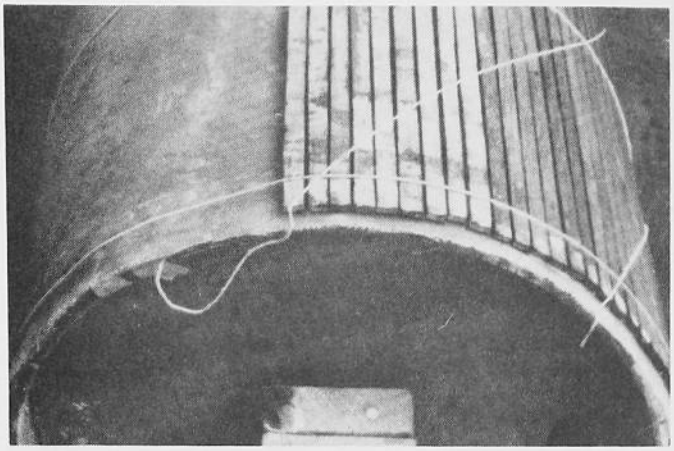
Its enticing qualities are that it is strong and light. I had never worked with fiberglass before, but figured there was always a first time. The idea was to first build a mold, then through successive wrappings of fiberglass, to build up a tube around the mold that was of sufficient wall thickness and strength.

Finding something to use as a mold posed nearly the same problem as building the tube—make it out of what? To my dismay, Sonotube of the correct diameter was unobtainable so I proceeded to make the mold. This was eventually constructed by taking a full 4' x 8' sheet of masonite and wrapping it into a tube. This was NOT easy. Masonite does not like to be bent! Eventually I succeeded, and several circular plywood disks were pounded into the mold to keep it round. A pipe was run through the center of the mold, so it could be rotated as the fiberglass was applied. Several gallons of epoxy resin (NOT polyester, which is much inferior to epoxy) were obtained along with many yards of fiberglass mat and cloth. Note—epoxy resin is not cheap, being around $40 a gallon (the last time I checked). The fiberglass mat, cloth, and resin were obtained from a mail order marine supply store—Defender Industries (P.O. Box 820, New Rochelle NY 10801-0820).

The first step was to wrap the mold in a thin (about 1/4 inch thick) sponge-like wrapping—something like foam rubber. This was followed by a wrapping of polyethylene painter's drop cloth (epoxy resin doesn't stick to this plastic). I hoped that after the tube was finished, the mold might be able to be easily slid out of the tube (and this was indeed the case).

After several wrappings of fiberglass mat and cloth, it became apparent that tube thickness was not building up very quickly, and the cost of the mat, cloth, and resin was not cheap. I had suspected that this would be the case beforehand, and that something would have to be used as a core material to build up tube wall thickness. The article I had read emphasized using foam as a core material, but this was quickly dismissed as not being rigid enough to hold the bolts for the mirror cell and the guidescope rings, or for keeping the tube sufficiently stiff. After much debating I settled on an experiment.

Two 1/4-inch lauan plywood sheets were purchased and strips one-half inch wide by 8 feet long were cut. Epoxy resin was painted on the layers of fiberglass now on the mold and was allowed to become tacky. The strips of plywood were then pressed onto the resin a few at a time and were allowed to cure. The mold was rotated until all of the tube's surface was cov-



Composite construction makes the tube both strong and lightweight. Shown here are some of the 102 thin strips of Lauan plywood over an inner layer of fiberglass. More resin and another layer of glass complete the structure.

ered with plywood strips. Very important, though, a small amount of space was left between each strip. After the surface was covered with plywood, epoxy resin was poured over the tube, filling in the gaps between the strips and sealing them. Altogether 102 lauan plywood strips were used. The plywood would form the core material of the tube. It would be a compromise between being light and being stiff and incompressible. More layers of fiberglass were wrapped around the plywood, forming the outer layer of the tube. The epoxy resin bonds the inner and outer fiberglass layers together (through the gaps between the strips) in sort of a miniature I-beam fashion, while the plywood gives the tube sufficient wall thickness and resulting strength. The tube was then alternately filled in spots with fiberglass auto body filler and laboriously hand sanded (wear a mask!). It was then painted. The finished tube is as smooth as glass.

Construction of the tube took most of my spare time during the summer of '84. The finished tube was trimmed to 7 feet 6 inches, is strong enough to stand (and jump!) on, is 17.5 inches in outside diameter and approximately 1/2 inch in wall thickness, and weighs 80 pounds. Perhaps there was a better way, but I can't knock this– it worked.

In order to baffle the inside of the tube, I purchased several yards of black felt. At first I feared that the felt would constantly be shedding on my mirror, but this has not proven to be the case. I also pondered whether the felt might help insulate the light path– reducing any tube wall currents. It may, though I can't claim this as a fact. The felt was adhered to the inside of the tube with Dap Weldwood acrylic latex (no-fumes) contact cement. This has worked very well. After several years use, none of the felt has come loose. The layup of the felt involved crawling inside the tube with felt, a paint brush, and some contact cement– quite an experience, but with an excellent result. (This adventure alone is a valid case for a larger tube– ie. bigger scope!).

Mounting #1: Solid as Steel?

The saga continued with the construction of the mounting.

The largest pillow blocks (two) I could find (2-7/16-inch diameter bore) were purchased to serve as the RA axis bearings. Each cost about $60. I found that black double thickness (known as schedule 80) plumbing pipe would just fit in the pillow blocks. The design of the mounting closely followed the description in the book I had– except as I said, I used a bit larger and heavier pipe. For the declination axis, I purchased two 1-15/16 flange bearings, through which, again, some black pipe just fit. In short, a considerable amount of 1/4-inch steel plate was obtained at a local scrap metal yard (for about 10 cents a pound) and this was very laboriously cut with a circular saw (using an abrasive metal blade) and hack saw, into parts that formed the equatorial wedge. A large piece of steel channel iron supported the pillow blocks and rested on the wedge. Throughout the winter, spring, and summer of 1985, I cut the steel for the mount, had it welded (I ended up being on a first-name basis with everyone in the welding shop), and assembled the mount. In the course of assembly I went through a circular saw, a vice, a drill, as well as countless files, drill bits, and hacksaw blades. Again, an experience. The resulting mount was– hefty. I built it with the idea of eventually setting it on a concrete pier. A commercially made 12-inch drive was obtained and was fitted on the RA axis. Considering what I had to work with (no machine tools) and some constraints imposed by pipe dimensions and shapes, the mount ended up being a nice piece of work.

Some large setting circles were made (a story in itself), and more steel plate was obtained, cut, and welded to form the saddle for the tube.

By this time, the tube had been cut and drilled to fit the mirror cell, focusser, and spider. The complete tube assembly weighs about 120 pounds (the primary is a 1:9 ratio mirror by Enterprise Optics). Also, during this time I built a temporary wooden pier which rolled out of my garage on 8 large rubber casters. The mounting was set on the pier, and eventually by late summer of '85, the tube assembly was placed on the mount. To counteract the weight of the tube, a large steel concrete-filled, 50-pound counterweight was made. Because of the weight of the tube assembly, the counterweight had to extend considerably out onto the end of the declination axis– something I was not too happy about.

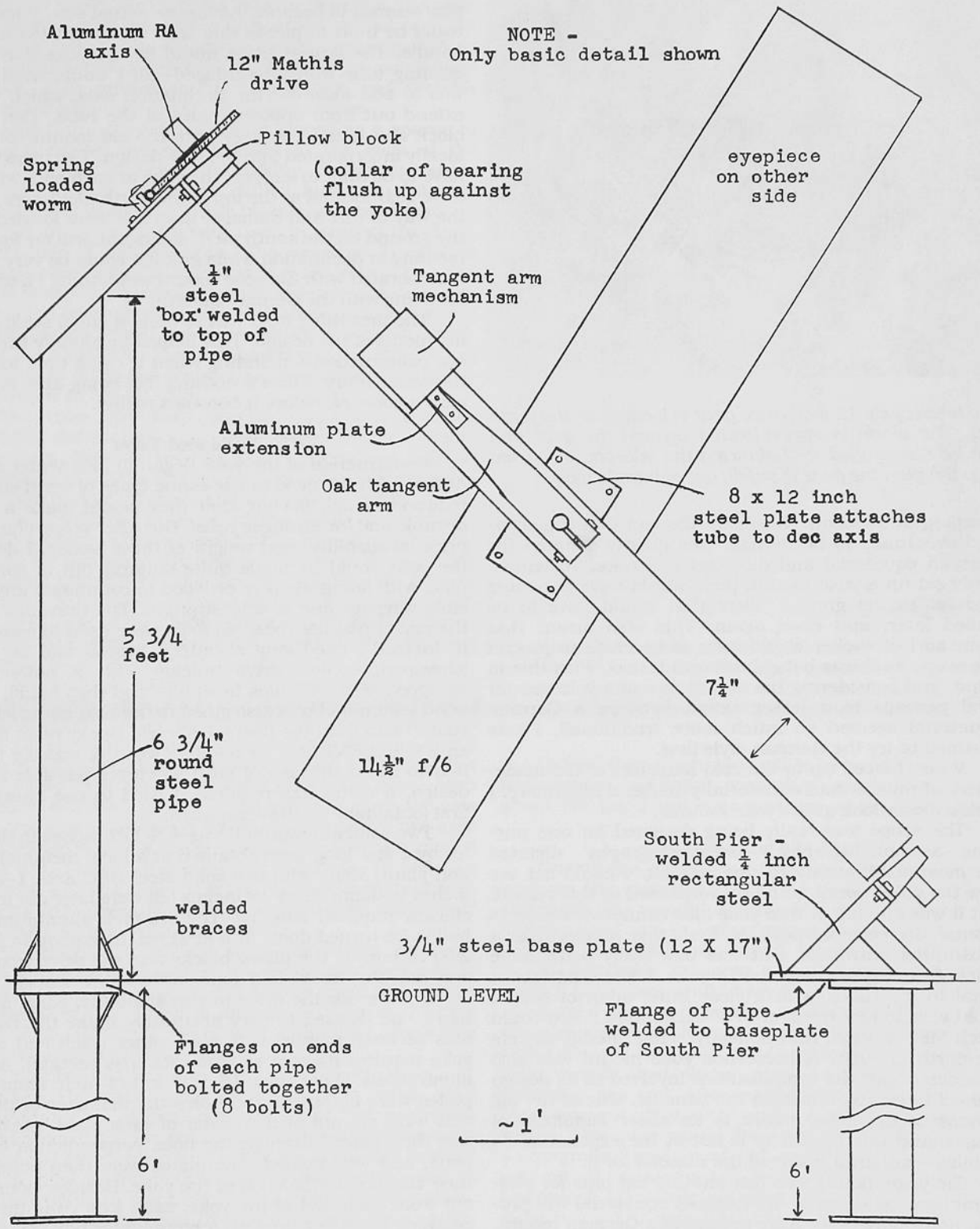
Lessons the Hard Way

As the scope was being finished, it was rolled in and out of my garage (or rather the landlord's!). It rolled easily, but to say the least, it was rather heavy. The eight wheels left indentations in the pavement each time the scope was rolled in and out, and left considerable dents in the pavement wherever it was parked!

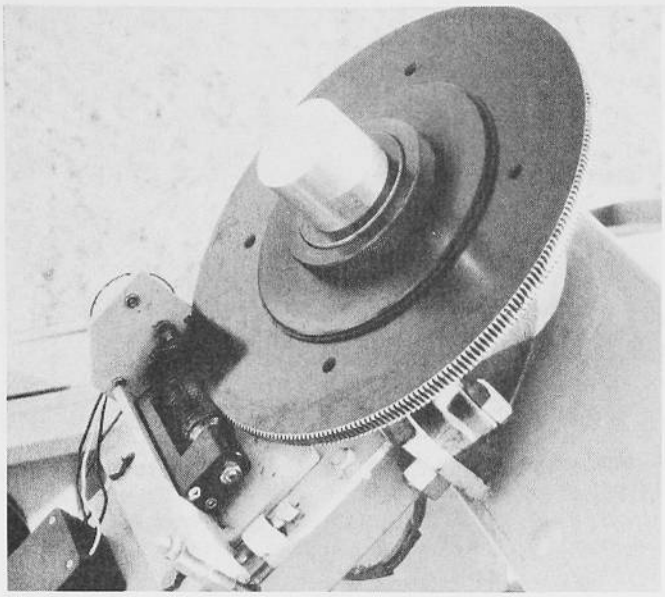
Though the mount proved adequate for visual use, it had become apparent during the latter stages of the design that it may not cut it for photography. The scope had a tendency to have a small amplitude, low frequency oscillation about the declination axis. I was also not pleased at how the pipes fit through the RA and DEC bearings (they had to be ever-so-slightly shimmed). The size of the required counterweight proved to be the proverbial straw on the camel's back (I strongly dislike counterweights). After a month or so of poking around the sky, enjoying sights with the 14-inch, reality set in. It wasn't going to cut it. Shortly thereafter, with the pillow blocks and drive salvaged, the mounting was dismantled and sold as scrap.

Lessons the Hard Way. Take 2: the Solidity and Simplicity of the Yoke Mount

When I first considered the mounting for my scope



View from the West



The telescope's 12-inch drive gear is located on the north pier. The worm is spring-loaded against the gear and can be disengaged for balancing the telescope. Perched atop the pier, the gear is safely out of harm's way.

(keeping in mind my situation—the fact that the scope had eventually to be moved), this greatly dictated the German equatorial and discounted a yoke. To temporarily set up a yoke mount, piers would have to be dug and set in the ground. Piers that would have to be pulled later, and reset again. This also meant that some sort of shelter would have to be made to protect the scope as it was being built and tested. With this in mind, and considering the overall size of a yoke mount (and perhaps to a lesser extent because a German equatorial seemed so much more traditional), I was destined to try the German style first.

When I faced up to the cold hard fact of the inadequacy of my German equatorial plumber's nightmare, I took a closer look at the yoke mount.

The scope was really being designed for one purpose—astrophotography. Astrophotography dictated the most solid, steady mount possible. I could not see how the yoke mount could be surpassed in this regard. But it was still big. A true yoke also cannot view objects around the celestial pole. At first, this seemed like a substantial drawback. But was this really bad? Some quick geometry showed that a yoke 8 feet long (about equal to my tube), with a clear inner span of 6 feet, could view to just north of +70° declination (i.e. it could reach M81 & M82). And honestly, what notable objects are north of +70°? A horseshoe yoke mount was also considered, but the complications involved in its design seemed to greatly outweigh the benefits. One of the big plusses of the yoke mount is its sheer simplicity of design. And this simplicity is not at the expense of its stability—rather, it is one of the reasons for it.

The yoke mount also has another big plus for photographers, as users of the German equatorial will profess; how many times have owners of a German mount, when photographing an object on the meridian (where all astrophotography should be done if possible), had to stop and roll their telescope over to the other side of the pier—as the object crossed the meridian? This was often an inconvenience for me when I used my old 6-inch. The beauty of the yoke mount is that it is IDEALLY configured for photography on the meridian. (This can't be overstated!)

The more I considered the yoke mount, the smaller it now seemed to become. As for the actual size, I figured it could be built in pieces that were really not too hard to handle. The largest piece would be the yoke itself. The existing tube would be utilized—all I would need to do was to add axles for the declination axis, which would extend out from opposite sides of the tube. The pillow block and flange bearings from the old mount could be ideally incorporated into the new design. Two piers would have to be built to support the yoke at each end, with the drive gear located at the top of the north pier (more out of the way of dirt and damage, than if it were located near the ground on the south pier). A tangent arm for fine corrections in declination while guiding could be very easily incorporated with the yoke mount (something I had trouble doing with the German mount).

The first thing I did was to build a small scale working model of the design. This helped invaluably throughout construction—including when it came time to build the observatory. There's nothing like being able to visualize a concept, before it becomes reality.

The Yoke and Tube

Construction of the yoke began in late winter of '86. At first I felt the need to use exotic types of wood such as redwood or oak (feeling that they would make a more durable and/or stronger yoke). But after researching the price, availability, and weight of these woods, I decided the yoke could be made quite suitably out of common pine, with laminations of plywood to counteract any possible warpage and to add strength. The drawings show the makeup of the yoke. No nails were used to construct it. Instead I used long sheetrock screws and lag bolts (sheetrock screws drive quickly with a power drill equipped with a Phillips head bit—and they hold!). Each wood lamination was also glued to the next using leftover epoxy resin from the fiberglass work. Epoxy resin makes an EXCELLENT glue for bonding wood! It was my intention to avoid the use of steel wherever possible in the design. If metal was required, I tried to use aluminum first (obtainable at the scrap yard).

Two solid aluminum RA axes 2-1/2 inches in diameter by 2 feet long were obtained at a local metal fabrication plant, along with two solid steel DEC axes 1-15/16 inches in diameter by 18 inches (all were later cut to specifically required lengths). The 2.5-inch aluminum axis had to be turned down at a local machine shop to fit the 2-7/16 bore of the pillow blocks and the drive gear (the only machine work I had done on the entire scope).

In order for the drive to run smoothly, some means had to be devised to very accurately make the two RA axis sections parallel with each other (each end of the yoke requires its own separate RA axis section). As the illustrations show, two 15 x 6 x 1/4-inch aluminum plates were obtained, and holes the diameter of the RA axis were cut out of the center of each plate. Each axis was then placed through the hole, perpendicular to the plate, and was welded. The plates were then bolted (at their corners) to the ends of the yoke. Besides extending out from each end of the yoke, each axis runs through enlarged holes cut through a rectangular box-like structure at opposite ends of the yoke. The inner end of each axis is held in a 3 point setscrew arrangement with setscrews 120° apart. Since each axis is held centered at the very end of the yoke by the aluminum plate, tightening down on the various setscrews causes the alumi-

num plate to deform slightly and changes the angle of each RA axis by a very small amount.

Final alignment of the RA axis was done after the north and south piers were finished, and the yoke was placed on them. Without the tube in the yoke, the yoke was rotated, and the eccentricity at the end of each RA axis was noted. The setscrews were then adjusted so that upon rotating the yoke, there was no perceptible runout. This proved to be an accurate and durable means for aligning the two RA axis sections.

Aluminum channel iron was placed as a spacer in the rectangular box-like sections at the ends of the yoke for added strength and rigidity. For added peace-of-mind, indentations were drilled into both RA axis sections into which the pillow block's setscrews rest.

The flange bearings were used to support the declination axis of the telescope. The bearings themselves were recessed into the inner sides of the yoke. The sides of the yoke were purposely built wide enough to incorporate the bearings and wide enough so as to not create a weak point where the bearings were located. Provisions were made so that one bearing had a short bit of mobility, to allow the declination axis to be aligned perpendicular to the RA axis.

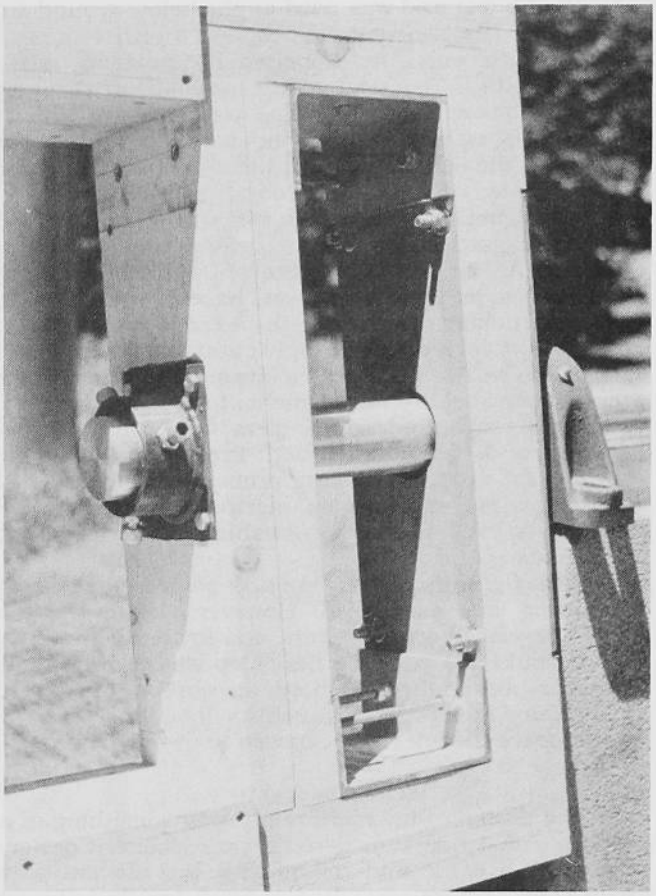
The tube was then modified to accept the two opposing declination axis. This proved to be a tricky procedure. How do you go about placing an axis on either side of a tube so they end up being exactly opposite and parallel? Not only that, but in order for the tube to be installed in the yoke, the design dictated that each axis had to be removable from the tube. (The procedure for installing the tube called for, first, installing each axis through its bearing; next, placing the tube in the yoke between each axes and then attaching each axis to its side of the tube). There was no way of attaching the two axes permanently to the tube and then inserting them through the bearings.

This dilemma was solved with the use of two 12 x 8 x 1/4-inch steel plates. Each DEC axis was welded exactly perpendicular to a plate. The surface of the tube was then prepared for accepting a plate by pouring epoxy resin in a mold on the tube which created a flat area. The plate could then be bolted to the side of the tube—after the tube had been placed in the yoke (between the axis and bearings). But to say the least, getting the two axes both opposite and parallel to each other was tricky. A great deal of careful measuring was done. In order to minimize any stress and flexure, all four bearings of both RA and DEC axis are made to mount flush up to their respective plates—with no overhang.

As designed, the tube does not rotate. In many ways this greatly simplified the design and may add to stability. The only objection is that a small area to the northwest of the zenith is difficult to view at the eyepiece. Still, all things considered, I have not found this to be much of an inconvenience.

Finishing touches were then made on the yoke.

First the rectangular ends of the yoke were enclosed with 1/4-inch plywood. Then for protection against moisture, the yoke was sealed with a generous painting of epoxy resin and sanded to a smooth finish. I then painted it with Petit EasyPoxy boat paint which is specially made to paint over epoxy resin and fiberglass. I can highly recommend this paint for use over epoxy, as it is incredibly durable. It is also not cheap, being better than $12.00 a quart. The tube was also finished with this paint and has held up very well. For colors, the tube was painted Ocean Blue, while the yoke and piers were painted Platinum—a light gray.



One end of the yoke under construction. The RA axis is welded to a steel plate and accurately aligned by means of three setscrews in a collar inside the yoke. The yoke box is closed in the completed telescope.

Overall the yoke turned out to be excellent, and perhaps ended up being somewhat overbuilt—it weighs about 160 lbs. There is no question as to its solidity.

Constructing the Piers

During the time I was finishing the yoke, I began work on the piers that would be needed to support it. The north pier would have to stand 6-1/2 feet tall at its highest point and be hefty enough to easily support the scope. The south pier would be much smaller, but would still have to carry a considerable amount of weight. Both piers would have to be built out of steel.

A good portion of my free time during August of '86 was devoted to making the piers. In the scrap yard I found three 8-foot long, 6-3/4-inch (outside diameter), thick-walled steel water pipes, each with a flange welded to one end. After getting them home, one of the pipes was cut off at a 45° angle, 5-3/4 feet up from the flange. This pipe would form the lower portion of the above-ground section of the north pier. At the top of this cut off I welded a 1/4-inch walled steel rectangular box (which I constructed), and at the end of the rectangular box a 1/2-inch thick steel plate was welded. This plate would eventually have the pillow block bolted to it. The 45° rectangular box overhang allows the yoke to rotate without restriction by the north pier. The overhang must be at least 1/2 the width of the yoke (plus a little bit). One of the other 6-3/4-inch pipes was cut to a

length of 6 feet and was used as the below-ground support pier. The two pipes are bolted together flange to flange, with only the uppermost pipe being visible above ground. To attest to the strength of the north pier, for the year that the scope was in Albany and was being finished and tested, the north pier essentially served as the sole support for the scope. The south pier merely rested on top of the ground.

Construction of the south pier was straightforward, though it again required a good deal of metal cutting and welding. A 12- x 17-inch piece of 3/4-inch thick steel plate serves as the ground-level base for the pier. Just prior to trucking the scope to the Adirondacks, I took the third 6-3/4-inch diameter pipe, cut it to 6 feet in length, and had it welded to the base plate of the south pier. This serves as the below-ground anchor to the south pier.

Both north and south piers were wire brushed, sanded, and then painted with Petit Rust Lock which is an excellent rust-resisting primer paint intended for painting metal surfaces in marine applications. Several coats were used. The finishing coat was of Petit EasyPoxy.

With the bulk of the yoke and piers completed, the mounting was assembled. However, before the tube could be placed on the mount and further work on the scope could be done, the next step was to construct a suitable observatory. Without an observatory at this point, any further work (such as installing the tube) would leave the telescope exposed to the elements.

The Observatory

The design of my observatory was something of an experiment. I had considered several different designs, including a dome and roll-off-roof, but all had drawbacks. And above all, I had to keep in mind the fact that the observatory had to eventually be disassembled and moved 120 miles in the back of my pickup truck!

Because of the bulkiness and difficulty of building a prefabricated dome, and to some extent because of the problems a dome can create with seeing, a dome was ruled out. Prior experience with a club-domed observatory also showed that if not carefully designed, they have a tendency to freeze shut in the winter.

Another consideration concerned my mounting. When the scope is pointed toward the horizons, the mount causes the scope's tube to be about 3 feet above ground. If I were to employ a dome, the walls could be no more than 3 feet high. Where would I put a door? (This is a very real consideration).

The rolloff-roof seemed to be a better alternative, but again, it had its own problems. If I rolled the roof off to the south, west, or east, it would substantially block my view of that horizon. If it rolled to the north, the design would be somewhat complex (to clear the top of the north pier). And still, where would I put a door? I wanted a full height door—something I wouldn't have to duck or crawl into.

The design which I came up with—the Hinged-Roof design—came about by allowing the telescope to dictate the form of the building. I had never seen this style of building before, and took a chance that it would actually work.

I must admit that the building was originally constructed as something of a temporary structure—just something to adequately house the scope for a few years until something better(?) could be built. Economy of both time and money was a great consideration at this point.

The first step in the observatory's construction was to build the four lower rectangular walls. The east and west walls are 10' 6" long by 3' high, and were constructed of 2 x 4, 4 x 4, and 1/2-inch plywood framing—all assembled with long sheetrock screws (very few nails were used). The lower north and south walls are similar but only 10 feet long. The walls bolt together at the corners. The gabled ends (north and south) are actually comprised of two pieces each, which are bolted together (and in the case of the north gabled end, is bolted to the north lower wall). Since the telescope is something of a tight fit in the building—it's basically a one-person observatory—the building had to be accurately aligned north and south in order to fit the piers and the scope itself. When the observatory was finally moved to and assembled in the Adirondacks, the walls were set to rest on (and bolted to) four 4 foot, 5 x 5-inch pressure-treated wooden posts set into the ground with 10 x 10-inch steel plates at their bases (the plates just keep the building anchored).

As the photos show, the roof of the hinged-roof design is split, in my case into four roughly 5 x 7-foot sections, with each section folding open on large hinges. To facilitate viewing to the south, the south gabled end is also designed to fold down to the ground on hinges. When the building is closed, it resembles a garden shed (or a chicken coop as was once stated). The rails of a rolloff-roof are not required. When the building is opened, the walls are 3 feet high and the view of the sky is completely unobstructed except for a small area from the north celestial pole, to the north horizon. Considering my mounting style and its inaccessibility to the area around the celestial pole, the building is a perfect complement to the scope. Also, because the north wall remains up a full height, the door can be placed in the wall. When the building is open, the top of the lower walls serves as a long shelf for placing items on—quite handy.

Furthermore, the roof can be opened in several different configurations. If viewing objects to the south, just the southeast, southwest, and south gabled end can be folded down. For example, sometimes for viewing and photographing comets low in the west after sunset, I just open the southwest and northwest sections of the roof. The telescope was designed to be able to turn inside the remaining sections. The yoke just clears the unopened roof sections.

The building also has much added appeal for those who live in snowy climates. As the aluminum roof is inclined at a 45° pitch, any snow that falls on it will soon, if not immediately, just slide right off. I have never had a clear night after a heavy snowfall, (or even after a severe ice storm), when I was shut down because of snow on the roof, or a roof that was frozen shut. This has proven to be a big plus. The building is solid and completely weathertight.

Prior to actual construction, a question remained: how much would the roof weigh? I estimated that making the roof in two sections (single piece east and west sections) would make it excessively heavy to open, but in four sections it would be quite manageable. Utilizing aluminum roofing sheets over a 2 x 4, 2 x 6, and furring strip framework. I made a reasonably light roof which is more than adequately strong.

To open the roof I use the following procedure: a 10-foot-long pole is kept in the building which has a metal hook at one end. Outside, near the peak of the roof, each section has a metal eye which screws down through the roof panel into the framework below. I

bring the pole outside, hook the hook through the eye, and pull the roof section open. For use at night, the pole has a small penlight flashlight taped to the end of the pole, near the hook. I would estimate it only requires a maximum of about 20 pounds of pull or lift to open or close a section, and requires only a couple minutes to have the roof completely open or to close it back up. When not in use, the roof is securely bolted shut inside the building with five large bolts and wing nuts.

The roof ridge is secured to the west roof sections only and lifts off with them. Also, the aluminum roofing of the southeast and southwest sections overlaps the northeast and northwest sections to form a weather-tight seal. As a result there is an order to how the roof sections must be opened (for example, a south section must be opened before a north one). Still, several partially opened configurations are possible. The door is nearly 6 feet high of solid wood, with a hefty lock.

When I first investigated the design, I assumed that suitably large hinges could be found in my area. When it came time to get them, none the type and size I required could be found, and even the small ones I found cost a small fortune (and this design requires ten hefty hinges). I ended up making my own hinges for a fraction of what I could have bought even smaller ones for, and they are of far superior quality.

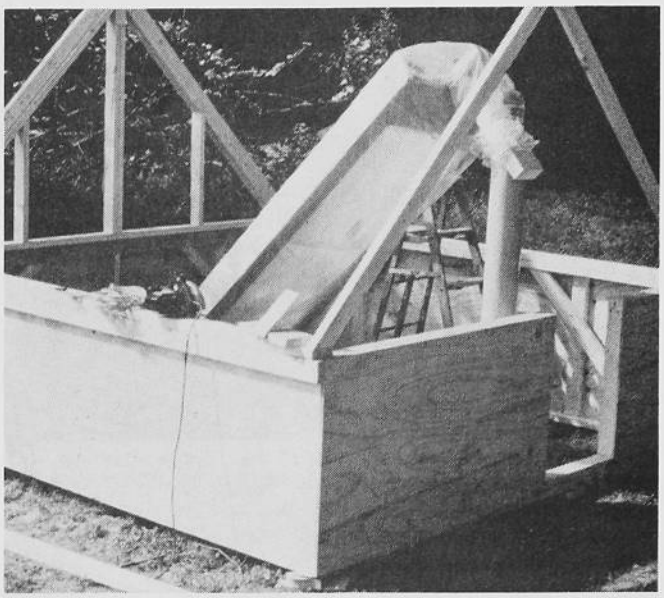
Each hinge was made as follows: two 4 x 8 x 1/4-inch metal plates were cut and were laid on top of each other (clamped together). A small pipe was laid along the long side the plates. The ends of this pipe were welded to the top plate, and the center of this pipe was welded to the bottom plate. The pipe was then cut in three pieces, with the cuts falling between the welds. A threaded rod was filed down just enough so that a hammer could tap it through the three sections of pipe. To prevent the rod from sliding out of the hinge, it was spot welded at the ends of the pipe. To complete the hinge, mounting holes were drilled in the plate, and countersunk to accept the bolt heads. Just look at a standard door butt hinge and you'll get the idea.

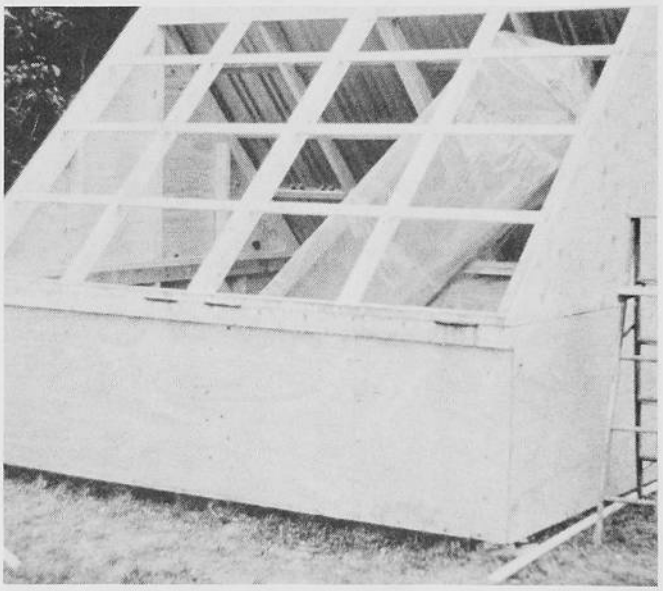
Trim and a generous painting, inside and out, of wood preservative stain completes the structure. The overall cost of the building was about $550.

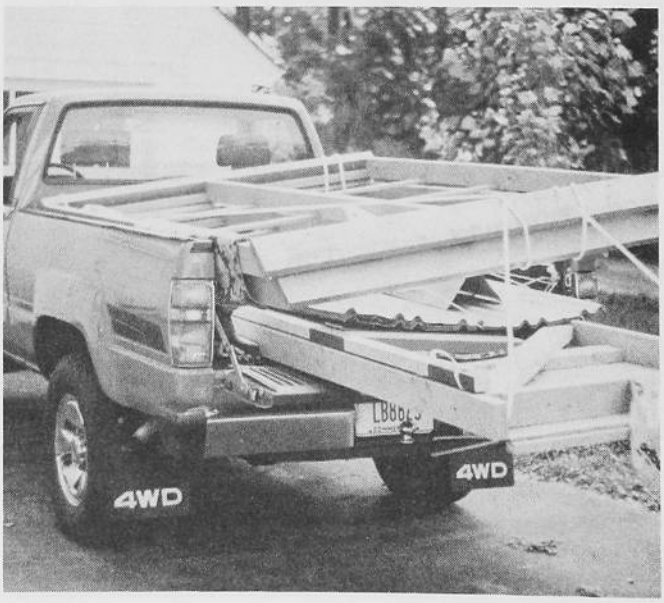
If I were to list any disadvantages to this style of observatory, I would have to note the scope and observer's lack of protection from dew and wind. Still, due to the steadiness of the yoke mount, I have been able to secure some nice photos in a moderate wind (which put a nearby SCT in a rolloff-roof photographically out of business). It can also be cold in the winter (at 20° below zero) when even the slightest breeze chills the fingers, and the scope is white with frost. Care should also be exercised in opening and closing the roof, as it does require a moderate amount of heft (I would not recommend this design for a club observatory where many different persons would use it). These would be considerations to take into account for anyone contemplating something similar.

The Final Stages

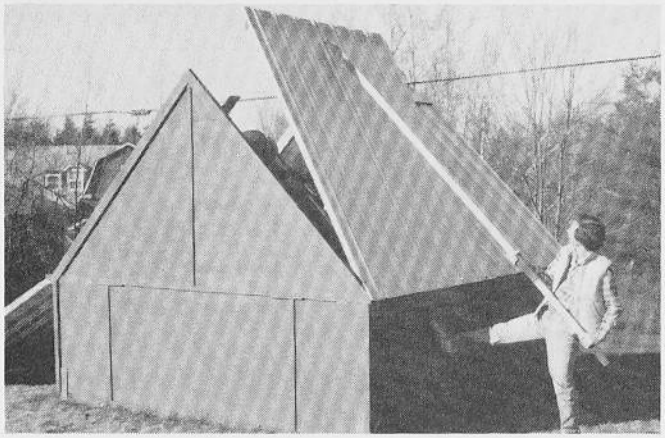
Prior to the move to the Adirondacks, with the observatory completed, the tube was installed and the finish work—installing the drive, tangent arm, wiring,







Construction on the roof began by framing the roof panels around the yoke (shown here wrapped in plastic). After the building was completed and tested, it was moved to a dark-sky site in the Adirondack Mountains.



guidescope, and various alignments—was begun. I also started some observing.

Installing a drive system on a yoke mount carries with it a bit of a twist. With the worm gear on the RA axis, the worm must (most likely), be set on the (north) pier. Since it is possible that the piers could shift slightly (with frost or settling), if the worm is bolted down rigidly to the north pier, a small shift of the pier could potentially damage the teeth of the gear or worm. To solve this, I devised a spring-loaded worm that would give in just such an instance.

The spring loaded worm also allows me to completely disengage the worm from the worm gear to fine tune the balance of the scope after adding an accessory such as a piggybacked wide-field scope. This has proven to be exceptionally handy. For smooth tracking, a properly balanced scope is an absolute must. (In my case, I have found the drive to run flawlessly when the scope has a slight tendency to turn eastward if the drive is disengaged—that is with the scope slightly heavier on its east side. This is due to the way the worm and worm gear mesh). The drive has a 12-inch aluminum gear and brass worm made by the Thomas Mathis Company, and it does a nice job.

A small screw allows me to fine adjust (limit) the mesh between the worm and worm gear. I usually set this so the gear and worm are almost, but not quite completely together. (If it's windy, I set the screw for a tighter fit. This noticeably improves the steadiness of the guide star in the eyepiece during wind gusts, but also loads the drive motor a bit more due to the increased friction). The gearing is kept very well greased. A plastic cover (not shown in the photos) is normally kept over the worm gear.

For a tangent arm, I had purposely purchased a declination axis that was too long and extended out from the west side of the yoke. On the axis, I attached a 20-inch long piece of oak which, with a bolt, could be clamped onto the declination axis. The other end of the oak tangent arm is attached to a piece of aluminum block, through which a motor driven 1/4-20 threaded rod moves the arm. The actual radius of the tangent arm, from the declination axis to the threaded rod is 21.1 inches. The tangent arm is very responsive, with very little to no backlash. The motor-driven, threaded rod assembly was found by accident in the scrap yard, while looking for other items. I found it lying at my feet—actually I stepped on it! (Hint—when clamping a wooden tangent arm around a metal axis, insert some plumber's teflon pipe tape between the wood and metal. It will make the axis turn much smoother and will eliminate squeaking that might otherwise occur).

Besides serving as a tangent arm, it also serves as an ajustable friction clutch and is used as the sole means for holding the telescope in declination on an object. The scope does not have any locks on either axis, it works strictly on friction (the RA drive gear has a friction clutch).

In order not to compromise the seeing conditions that this style of building has to offer, any sort of stone or concrete floor was out of the question (the required move also ruled this out). Instead I settled on the following: first the dirt floor was sloped slightly. Then, a couple

Ready for observing! Using a pole with a hook on the end, George Viscome opens the southeast 5-by-7-foot panel. With the observatory partially opened, the telescope can reach the southern half of the sky.

layers of plastic drop cloth were laid down on the floor. This was followed by some black insulation board (a kind of 4 x 8 foot fiberboard covered on all sides with a tarlike substance). This was cut to fill in the floor space. On top of that I laid some indoor-outdoor carpet. This flooring has proven ideal—nice and comfortable to work on, and the thermal properties are excellent.

Finishing work involved mounting a 3-1/4-inch Jaeger's guidescope (an f/15 refractor I bought at the swap tables at Stellafane) on the tube using rigid aluminum guidescope rings which I fashioned myself. Because the guidescope is located toward the mirror end of the tube, it had to be offset from the tube by a couple inches in order for the guidescope's view to clear the front end of the main tube. The location of the guidescope has proven to be ideal. Using a mirror diagonal, I can sit in a chair and guide, though at other times it involves kneeling or sitting on the floor.

Since the guidescope offsets the balance of the tube, I later placed a small set of adjustable counterweights on the opposite side of the tube from the guidescope. In order to fine balance the scope in RA, a small counterweight was installed at the inside bottom part of the yoke. Again, having a scope that is properly balanced is very important to insure smooth guiding, and in order not to overload a drive. One of the big pluses of a yoke mount is that it requires very little (if any) counterbalancing.

One small item worthy of note that I added (which I feel is worth its weight in gold), was an Amici prism to the scope's 8 x 50 finder. Not only does it give the convenience of viewing at a 90° angle, but the sky is oriented as it is seen to the naked eye. No more turning charts upside down! For those who do a lot of star hopping, I highly recommend one.

By the spring of '87 the telescope was deemed a complete success, and I was even able to obtain some reasonably good deep-sky photos, despite the heavy light pollution of Albany.

From the very start of this project, to its completion, the scope took me 3-1/2 years to finish. Whereas the construction of the observatory took about a month and a half of spare time.

Moving On: a Quest for Dark Skies

During the time the scope was being constructed in Albany, I did some surveying of sites in the Adirondacks (where the scope was intended to be located). As my parent's home in Lake Placid is near the center of town, their location was not suitable. I had made a tentative arrangement with a farmer I knew to place it out in his field, but I wasn't very comfortable with the idea.

At about the time I was completing the scope, I learned of a newly formed organization (the Tri-Lakes Astronomical Society) situated near where I wanted to place my scope. As a result, I became acquainted with a member who was also heavily interested in astrophotography, and he gratefully offered me a site on his property—next to a rolloff-roof he had built for his scope.

In August of '87 the scope was disassembled in Albany, and six pickup truck loads were required to move the sections of the scope and building 130 miles to the new site. Assembly went as planned, and very careful attention was paid to aligning the mount. The north and south piers were set in the ground by packing dirt around them—no concrete was used. After several years of use, I have detected no shift in the piers, and very little correction in declination is needed when doing photography.

Performance

Overall I am very pleased with the performance of the scope. It has surpassed my expectations in most every way. For stability, it's hard to beat. It admirably passes the thump test—bumping the scope near the eyepiece. Vibrations die down very quickly. The movement of the scope is exceptionally smooth. Several years of use have shown the scope to require very little maintenance, with no downtime. I would not hesitate to recommend the yoke mount—its merits far outweigh any drawbacks. It is IDEAL for photography.

I have since added a quartz-controlled drive corrector I built around a circuit board purchased from Willmann-Bell. It was built to run on both 120 volts AC and 12 volts DC. A pushbutton control paddle controls both axes, and the brightness of the reticle in the guide eyepiece.

Even though the tube is very rigid, I found that exposures of 15 to 20 minutes, using the guidescope, sometimes resulted in slightly oblong star images due to the inescapable effects of flexure. I now use an off-axis guider almost exclusively to get perfectly round star images every time. The convenience of the guidescope is still used, but is reserved for guiding photos with wide-field cameras or for short exposures through the 14-inch. Plans are to soon employ a CCD autoguider and imager to further realize the capabilities of the scope and to allow me a bit more time enjoy the sky and not stare at crosshairs all night long.

Using a cold camera (a commercial unit—though I would eventually like to design my own), I can reach to magnitude 18 with a 10-minute exposure using Tri-X. A tank of compressed carbon dioxide supplies the dry ice.

The east declination axis extends out of the yoke, and I often mount a 3-inch f/6.6 refractor on it for wide-field shots. An 8-inch f/5.5 mirror I recently completed will soon become the heart for another scope that will be piggybacked on the 14-inch.

Despite the substantial amount of cloudy weather in the Adirondacks (it's clear an average of only one night a week), and the drive involved to get to the telescope, I have been able to build a collection of nearly 1500 respectable astrophotos (the first 250 done with the 6-inch).

In order to put my photography to interesting and practical use, I often employ a blink comparator I built (blue ribbon at Stellafane in '87), along with a computer program I recently wrote—called APPULSE—which finds appulses between deep-sky objects and minor planets and/or comets. (Anyone interested in a shareware version of this program can obtain a copy from me for $2 to cover the cost of disk, mailer, and postage).

Although the building was intended as something of a temporary structure, its ease of use and lack of maintenance have left me with little complaint.

As I stated, much of the design of the scope and especially the observatory was a bit of an experiment. The key is to define your goals, and let the goals dictate the design. There is nothing like a scope that is custom tailored to the job at hand—especially one which you have designed yourself. I hope that some of the concepts presented here might help give you some ideas to incorporate into your own TM plans.

Now, as for the next step, in the near future I hope to move the scope to a dark location in a backyard of my own.

George R. Viscome
100 Sentinel Road
Lake Placid, NY 12946

Stellafane '90

Stellafane, the grandaddy of astronomical conventions, is steeped in history and tradition. But after 55 conventions, change is inevitable. The organizers have had to adapt the convention to increasing attendance and the strain it puts on the grounds and facilities.

The 1990 convention was actually split in two. Breezy Hill was reserved for the telescopes, and the large tent that used to house the talks was moved from behind the now-famous pink clubhouse to the new camping area. People consequently found themselves obliged to make a 10-minute trek between areas to take in the whole convention. The road passes the old camping field, still strong with memories, but now sporting rows of Christmas trees. I heard one attendee say that he could not bear to look at the field as he hurried past it.

But with change come some good things. A welcome feature of the new Stellafane is the amphitheater for the Friday and Saturday evening talks. Instead of being sardined into the tent, people were spread out over the hill under the stars. Should the sky threaten rain, the tent is always available as a back-up. Although the skies looked threatening Friday night, clear weather prevailed all weekend.

Saturday morning came a little too early because much observing prevailed after the informal talks Friday night. At 8:00 a.m. the madness had started and the swap tables were buzzing with activity. I made my way down the hill that doubles as the amphitheater to the ravine where the tables were set up.

Row upon row of knee-high Christmas trees now fill the field at Stellafane where two generations of amateur astronomers once camped.

Last year the swap meet was a wash out; people slid down the hill and the swap area was sometimes ankle-deep in mud. That experience made me long for the dry, dusty climate of the Riverside Telescope Makers Conference in southern California. Thankfully this year we were spared the mud. Despite a few temptations, I stopped myself from buying things that would have probably ended up in my "interesting to have but not very useful" pile of junk at home. Now that I have attended both Riverside and Stellafane many times I have almost worked my way out of the obsessive desire to collect anything having to do with telescopes. Almost.

The tent is always full for the Saturday afternoon talks. This year three speakers were featured in the program: John Briggs on Group 70, Ethan Harris on building an interferometer, and yours truly on telescope performance. John Briggs, a Stellafane veteran and a member of Group 70, spoke on that California organization's efforts to build a 72-inch telescope. John updated the crowd on Group 70's progress. The project is well underway, with a grinding and polishing machine nearing completion. Although he came armed with a tray of impressive slides, John couldn't show them because the tent was too bright. This seriously limits speak-

Rick Moorman and Walter "Bud" Law demonstrate their motorized "Star Car" that allows two astronomers to view with 80mm binoculars.

ers whose slides are important to their presentation. Fixing it should be high on the list of things to change for future Stellafanes.

I presented a talk on the factors that affect telescope performance, highlighting the bum rap fast reflectors have been getting from observers. The blurring one sees at the edge of the field of view of f/5 and faster Newtonians is due to astigmatism—not coma—and it originates in the eyepiece rather than the mirror. The primary mirror's coma is completely overwhelmed by eyepiece astigmatism. Nagler-type eyepieces have very little astigmatism and that is the reason they work so well with fast reflectors. I was really looking forward to Ethan Harris's talk on interferometers but unfortunately he was not able to attend the conference. Instead, Tony Costanzano of the Boston ATMs, with the help of master of ceremonies Scott Milligan, demonstrated silvering a mirror.

I spent all of Saturday wandering around Breezy Hill and the camping field photographing people and telescopes. My wife Darlene helped by taking careful notes of who we talked to and what we saw. With the hill no longer the place to be, it seemed strangely quiet. At past Stellafanes, when the clubhouse area was the focus of attention, there always seemed to be hundreds of people milling around. This year that hubbub of voices and people seemed to be missing.

It appears to me that the number of homemade telescopes exhibited at Riverside and Stellafane in 1990 was down somewhat. It made me wonder whether telescope making might be in a bit of a slump. Perhaps the recent revelations of spotty commercial optical quality will inspire individuals to once again consider doing their own optical work. I am confident that the TM's first mirror will probably give the commercial products a run for the money.

Although the numbers were down, the telescopes on the hill were of exceptional quality. John Lawson, an optical designer from Dayton, Ohio, showed off his 12-

An audience gathers in the Stellafane amphitheater, one of two hubs at the convention. The other remains the famous pink house on the hill.

inch Wright-Schmidt-Newtonian with optics made by Optron over 20 years ago. The Surrier truss tube assembly weighs 60 pounds and sports a vented mirror cell to cut down on tube currents fueled by a warm mirror. The drive features a 10 times DC slewing motor operating through a differential gear. The declination motor is off a film dryer.

The most exotic optical design on the hill was Brian Lareau's 8-inch Buchroeder Tri-Schiefspiegler. It featured optical work by Dick Wesley. Compare Brian's tube design with the instruments pictured in *TM#35* and *TM#28*. Brian's idea of sending the light from the last mirror reflection through the declination axis makes the whole telescope very compact. I found the telescope worked every bit as well as it looked: views of Saturn were exceptional. Brian's novel telescope received top honors in the categories of design ingenuity and craftsmanship.

Walter "Bud" Law and Rick Moorman drew a lot of attention with the "Star Car," their solution to neck-breaking binocular observing. The altitude and azimuth axes are motor-driven and give the observers comfortable access to all parts of the sky. I was looking forward to observing Comet Levy with the Star Car on Saturday night, but I found that only the altitude axis was connected. Slewing around in altitude was great fun anyway. The Star Car received an award as a special exhibit. The guys say the next step is installing refreshment holders.

Telescope makers find parts in the strangest places. Chuck McLaun of Adenberg, Pennsylvania, discovered the heart of his telescope masquerading as a toy for lions at the zoo. The 20-inch diameter "Zoomer Ball" holds a 10-inch mirror and is the spherical base for an Astroscan-type telescope. I found the plastic-on-wood bearings a bit too sticky, but three little tabs of Teflon in just the right places would probably cure the problem. If you want to try a Zoomer Ball telescope write to Box 83, Greyslake, Illinois 60030, or call (312) 546-6125. Zoomer Balls come as large as 20 inches in diameter.

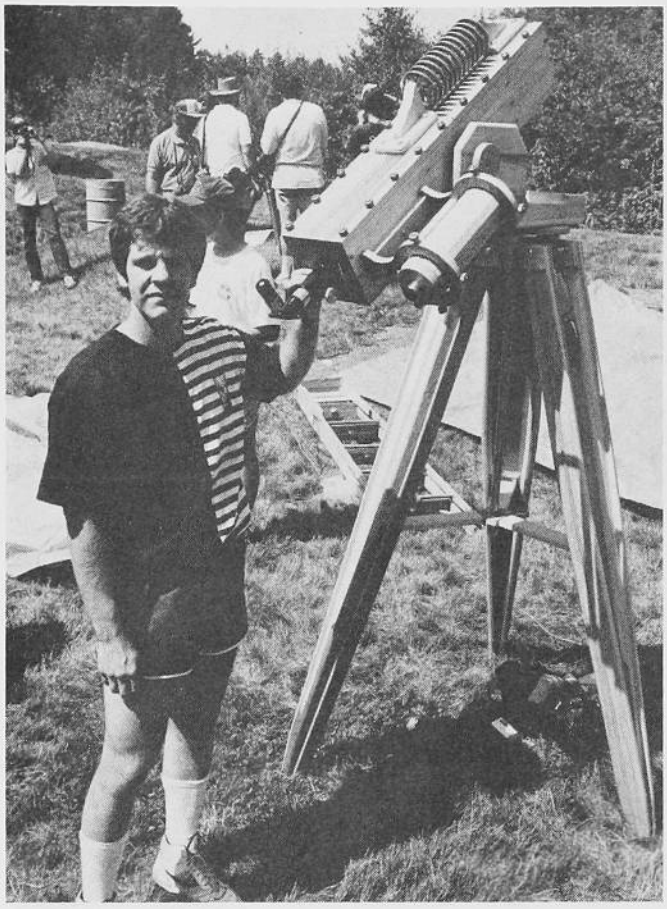
Canadian telescope-maker Max Stuart from Ottawa, Ontario, displayed his 4.25-inch Schiefspiegler, affectionately called the "Sheep-sprinkler." The fine workmanship did not go unnoticed—Max ran away with awards in both design ingenuity and craftsmanship. The slow-motion controls on the tangent arm drive and the declination axis worked very smoothly and made high-power observing a breeze.

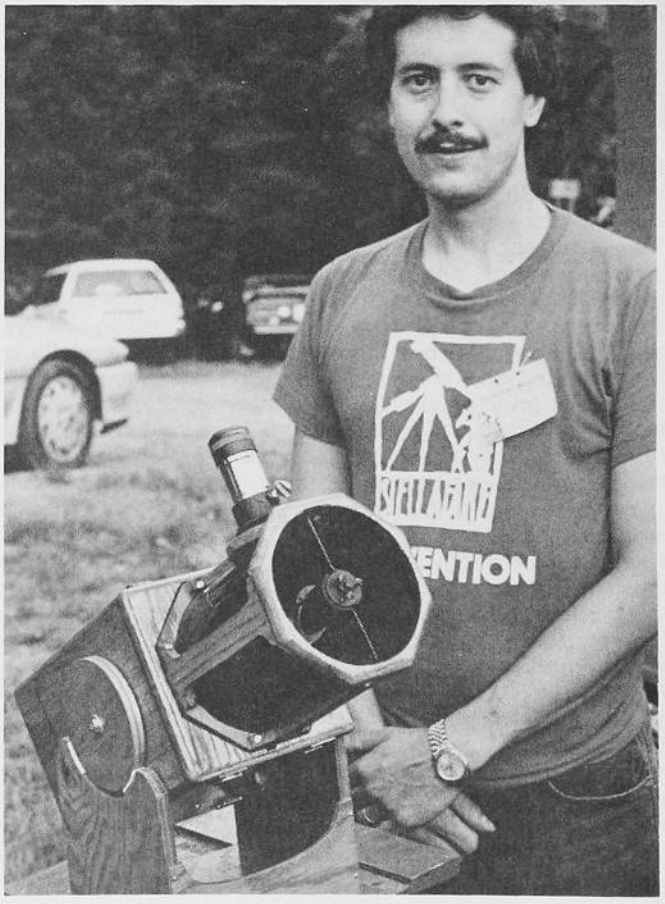
Not all the interesting telescopes were on Breezy Hill. I spotted Bob Schepis' tiny 4.25-inch Dobsonian in the parking area. Bob graciously let his chicken dinner get cold while

I snapped a few pictures of his break-apart telescope. After he puts a protective cover over the mirror, the front section of the tube is turned around and occupies the space in the rocker box, making the whole assembly really compact. So much so that Bob has lost it a few times among all his camping gear! I was really impressed with the quality wood-working and just how well thought out the design was. This telescope was not slapped together.

Many of the telescopes I have seen over the years are finely engineered instruments. A great deal of energy is expended making the mechanics sound. Too often, though, important refinements are forgotten or not considered at all. Although a telescope tube's main function is to hold the optics in alignment, just as important is its role in blocking stray light. Mary and Neil Hunt of Oakville, Ontario, refined their 10-inch Dobsonian for high-contrast observing. The interior of the tube is covered with black velvet to inhibit reflections and a tube extension helps reduce scattered light. The space between the primary mirror's edge and the inside of the tube is an excellent source of stray light. This light finds its way to the eyepiece and fogs the field, especially when the ground is covered with snow. Neil placed a light stop behind the mirror cell wide enough to block the stray light but still allow air to flow freely and allow the mirror to reach thermal equilibrium quickly. Note also the black paint around the upper section of tube around the eyepiece holder. A white tube can be annoyingly bright even at a dark observing site. The final touch is an observing hood to really put you in the dark and bring out those faint fuzzies from a seemingly pitch-black field of view. For a few other ideas on telescope refinement and baffling see "Ten Tips for Improving Your Telescope" by Alister Ling, in the August issue of ASTRONOMY, and Richard Berry's story, "Inside the Well-Baffled Newtonian," published in *Deep Sky #25*, Winter 1988-89.

There are times, of course, when a highly finessed telescope would be impossibly large and cumbersome. Large-aperture portable telescopes do require some trade-offs. Robert Horton of Kingston, New York, made his 17.5-inch reflector portable by eliminating the bulkiest part of his telescope—the tube. The diagonal is supported by a two-vane spider and a tension-wire reinforced strut assembly. Much of the stray light that might otherwise reach the observer is blocked by the circular baffle between the diagonal and eyepiece holder. A hole in the baffle is just large enough to admit light from the diagonal and primary, but the baffle blocks direct sky light and keeps it from flooding the field. Bob said that he did not notice any diffraction effects caused by the circular baffle. The entire diagonal support and eyepiece holder is fastened to a board that slides between the two main support struts. Focusing

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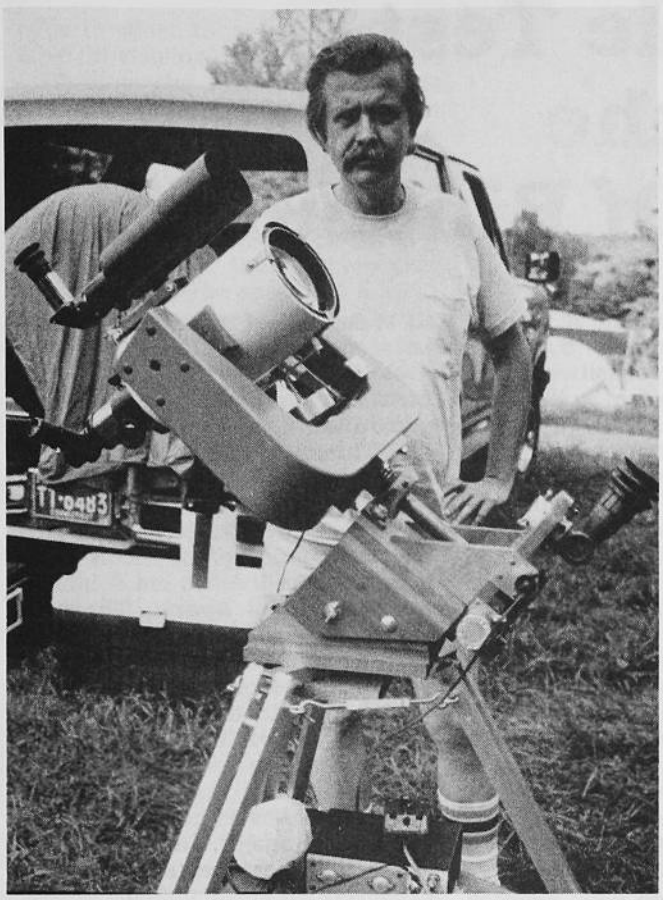
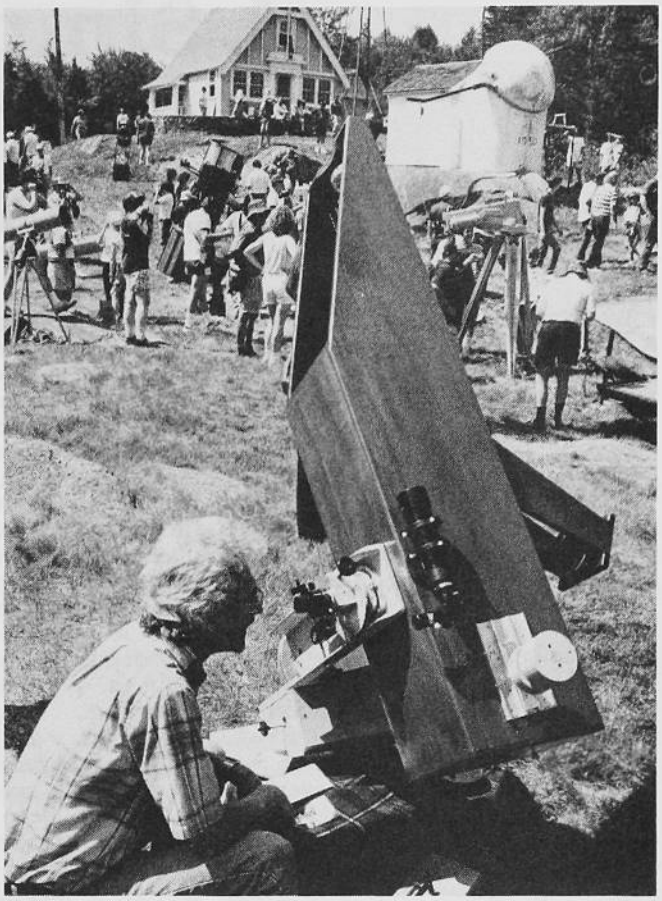




Mike Gean's 4-inch f/9 (left, top) and Bob Schepis' 4.25-inch mini-Dob shared wood. Mary and Neil Hunt's Dobsonian (lower left) and Chuck McLaun's Zoomer-Ball had only aperture (10 inches) in common. Bob Geiste (above) showed an 18-inch-focus swap-table photographic lens; and Brian Lareau and Dick Wesly's 8-inch Tri-Schief was most exotic.

is achieved by rotating a knob on a threaded bolt.

This year was very special in the annals of Stellafane lore because the site was declared a national historic landmark. A representative of the Secretary of the Interior and National Park Service was on hand to present organizers with a plaque commemorating Stellafane's new status, the highest honor the country can bestow. The Saturday night talks that followed were exceptional for the quality of the speakers and the absence of Walter Scott Houston and his traditional "Shadowgram" talk. Scotty was in Brussels attending a meeting of European Astronomical Association.

However, a highlight speaker not listed in the program was Dr. Albert Boggess, project scientist on the *Hubble Space Telescope* program. Representing astronomer-astronaut Steve Hauley, Dr. Boggess presented the editors of *S&T* with one of the *Hubble* "witness mirrors" for accurate reporting on the *HST* over the many decades that the project has spanned. A witness piece is a small mirror that receives the same coating and handling and is stored in the same environment as the HST optics. The effects of storage can then be studied on the witness without disturbing the main optics.

Dr. Boggess then bravely described *HST*'s severe spherical aberration problem to a knowledgeable and highly critical audience. While it was too early to identify the source of the error, Dr. Boggess explained how the spherical aberration could be eliminated with corrective optics in the new WF/PC camera scheduled to be sent aloft in 1993. He also talked about the 0.1-arcsecond jitter caused by the thermal shock the solar panels undergo upon entering and exiting Earth's shadow. New software will compensate for this effect.

During the presentation I noticed some people around me looking up and pointing to the sky. A very bright satellite was streaking across the sky. How ironic if it turned out to be *Hubble*! But the *HST*'s low-inclination orbit barely brings it above the horizon at this latitude and the north-south direction of the satellite meant it was in a near-polar orbit. Later I was informed by people in the know that the only very bright satellites in a polar orbit are the KH11 and KH12 spy satellites staring down on us. These satellites are twins of *Hubble*, but with great optics looking the wrong way.

This year's keynote speaker was comet-hunter and writer David Levy of Tucson, with a talk entitled "Comet Hunting: A Personal Perspective." David did not speak of the technicalities of comet hunting; instead, he went to the heart of the matter and spoke of the effect that this unusual pastime has on its participants, including himself.

The improvements to the Stellafane site, the excellent speakers, and the very good weather made this year's Stellafane gathering one of the best. And it isn't the telescopes but the people that continue to draw me to astronomy conventions all over North America. I encourage all *TM* readers to attend at least one of these gatherings.

—Peter Ceravolo

A Simple Test of the Collimation Of Binoculars

When you purchase or construct a binocular, one of your primary concerns is the parallelism of the two optical axes, of their collimation. When you view objects at a great distance, the eyes of the observer are aligned; that is, their visual axes are parallel. With a properly collimated binocular, the visual axes of your eyes are also parallel, and your eyes are relaxed and comfortable.

However, when you place misaligned binoculars before the eyes, in order to fuse the images from the two telescopes, your eyes are forced out of parallel. The eyes can adapt to this to a remarkable degree, so much so that you may not even be aware of the misalignment. However, the stress of prolonged or periodic misalignment results in fatigue, eyestrain, blur, and even headache. This paper describes a simple yet accurate means for measuring the collimation of binoculars, and recommends a maximum tolerance for misalignment.

Binocular Collimation

A binocular consists of two telescopes. In a collimated binocular, the axes of the two telescopes are parallel, and a beam of light entering the two telescopes from any angle also exits the oculars parallel.

Now consider a misaligned binocular deflects parallel rays entering either the objectives (labeled "obj" in Figure 1) or the oculars (labeled "oc"). In Figure 1, one barrel is assumed to have its optical axis parallel to the incoming light. The other barrel is out of parallel by the angle α. The dotted line represents the optical axis of the misaligned telescope.

Note that for light entering the objectives, the angular misalignment demanded of the eyes, γ, is much larger than α. In fact, $\gamma=(m-1)\alpha$, where m is the magnification from the binoculars. The telescopes in the figure diverge toward the oculars, and although the exit rays converge, the eyes must diverge to fuse the images from the telescopes.

Because the eyes will adjust to moderate misalignment, it is difficult to assess collimation by simple inspection. A more sensitive test is needed to determine collimation accurately. Although there are a number of different types of collimators, all share the drawback that they are not worth constructing for the collimation of one pair of binoculars. A good review is by Hanna in *Amateur Telescope Making, Book 3* (1). Another simple system that uses a projection of the sun is described by Luck (2) but it still requires the construction of some apparatus.

However, a simple field test which requires no special equipment yet is quantitative and accurate has apparently been overlooked. The only test equipment required is a telescope whose aperture is large enough to include at least some of the area of each objective of the binoculars to be tested.

To conduct this test, the binoculars are reversed so that the objectives are aimed down the tube of the telescope. The observer looks through the eyepiece of the telescope at a distant object. If collimation is perfect, the observer will see a single image from the binoculars. If there is a collimation error, the observer will see a double image. Because collimation is almost never perfect, that is the usually case.

If the distant object is the moon, the test becomes quantitative because the moon is almost exactly 1/2 degree in diameter. It can serve as a scale to determine the angular separation of the two lunar images.

How to Perform the Test

This test is performed as follows:

1) Adjust the separation of the binoculars to match that of your eyes. Focus each telescope of the binocular on the moon.

2) Center and focus the moon in the telescope.

3) Reverse the binoculars in front of the telescope (so moonlight enters the eyepieces) and swivel the binoculars until you can see two small images of the moon from the binocular through the telescope eyepiece.

4) Make one of two possible measurements:

4a) Using only the pair of small binocular images, estimate their separation (δ) as the number of small lunar diameters ($\Delta\delta$) that separate corresponding edges.

4b) Alternatively, estimate what fraction of the diameter of the large telescopic image of the moon (T) the separation of the two small binocular images (δ) spans. Then $\gamma = (\delta/2\Delta\delta)$ or $\gamma = (\delta m/2T)$.

Then, in either case $\alpha=\gamma/(m-1)$.

If you have oriented the binoculars relative to the telescope's eyepiece as shown in Figure 2, then the separation of the binocular images parallel to the telescope tube (δH) indicates horizontal binocular misalignment, and perpendicular to the telescope tube (δV) indicates vertical misalignment.

You can determine whether the binocular optical axes converge or diverge toward the ocular end by covering one of the binocular eyepieces. If covering the binocular eyepiece farthest from the telescope's eyepiece makes the image closest to the binoculars disappear, the binoculars are misaligned divergently, and *vice versa*.

How the Test Works

The optics of the test are shown in Figure 3. When the binoculars are reversed as with the field test, the misalignment, α, of the two barrels causes light to enter the telescope tube at an angle $\phi=\alpha(1-(1/m))$. Thus, the total angular misalignment seen at the eyepiece is $\delta=M\phi$, where M is the magnification of the telescope. Because the telescope increases ϕ and the angular diameter of the moon by the same amount, the magnification M of the telescope is not relevant except that it must be low enough so that the large telescopic image of the moon and the smaller binocular images of the moon should fit within the same field of view.

Although γ is an intermediate step toward finding α, δ is the more relevant quantity because it represents the misalignment required of the

eyes. In effect, the angle δ is responsible for viewing discomfort.

Because the eyes can adjust to some binocular misalignment, what limits should be placed on γ? This depends on the direction of misalignment. The eyes can cope better when they must converge (that is receive divergent light from converging binoculars) than when they must diverge. The eyes do not tolerate vertical misalignment at all well.

Johnson (3) gives the following recommended values for γ: horizontal convergence 2 degrees, horizontal divergence 1 degree, and vertical vergence 0.5 degree. These criteria are no doubt a bit strict, but they can be easily attained.

A Practical Example

As an example, I tested this technique on my personal pair of 7X50 binoculars. Using an 8-inch Newtonian telescope at 34 power, I observed the corresponding edges of the two binocular images of the moon to be separated by about 3.5 times their diameters ($\delta=3.5\Delta\delta$) along a line parallel to the length of the telescope. Thus, $\gamma=(\delta/2\Delta\delta)=$ 1.75 degrees of horizontal misalignment, and $\alpha=\gamma/(m-1)=1.75/(7-1)=$ 0.29 degrees.

Alternatively, the horizontal separation of the two binocular images (δ) appeared to span almost precisely 1/2 of the moon's diameter (T). Thus, $\gamma=(\delta m/2T)=0.5(7)/(1/2)$ $=1.75$ degrees, and $\alpha=\gamma/(m-1)$ $=1.75/(7-1)=0.29$ degrees. The results of these two estimates are no doubt so close only by coincidence. These binoculars were divergent and thus they fail Johnson's criteria. (If they had been convergent they would have passed.) Vertical misalignment was negligible.

To check the results of the field test I aligned two laser beams so that they were parallel and then passed each through the centers of the binocular objectives. The beams exiting the eyepieces gave $\gamma = 1.63$ degrees and $\alpha= 0.27$ degrees, which agrees well with the field test.

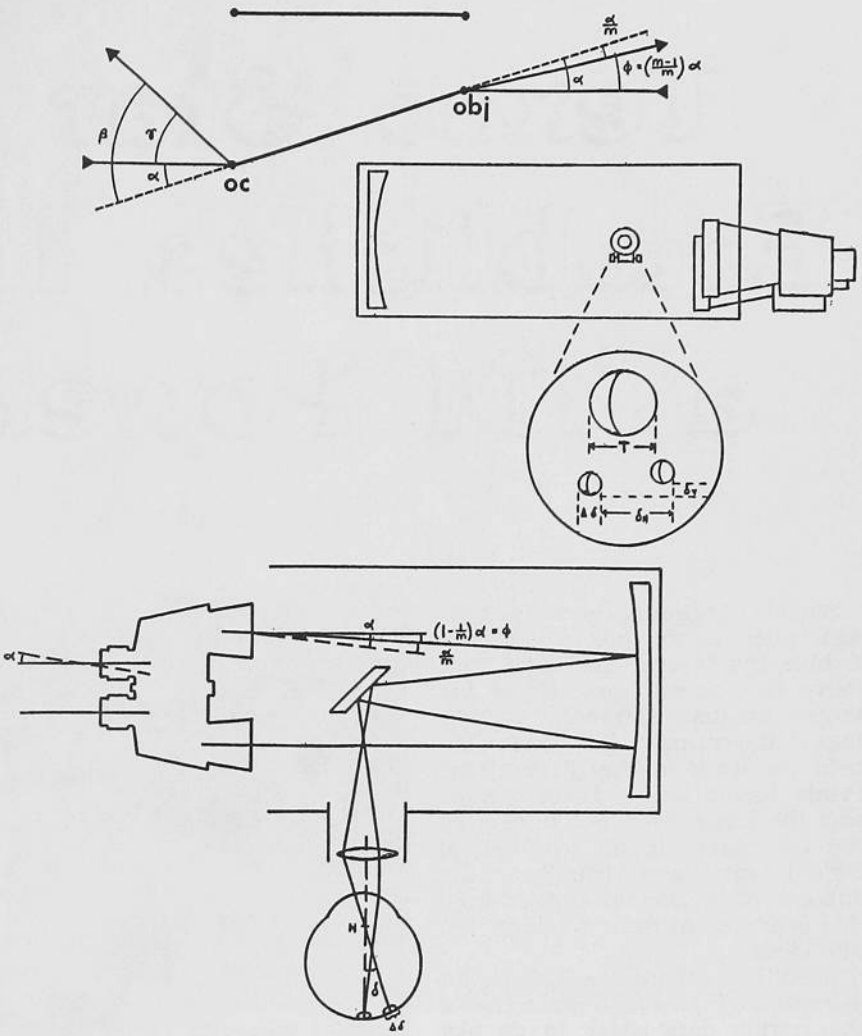
If you don't like the math, there's an easier way to judge whether a given binocular passes or fails the test. Simply determine the number of binocular lunar diameters that separate the two binocular images. They should be separated vertically by no more than one lunar diameter and horizontally by two diameters if the binoculars are diverging, and by no more than four diameters if they are converging.

Here are a few tips:

1) If the moon is near full, the pupil of the eye may constrict so that it is no longer large enough to accept enough of the exit pupil of the eyepiece to include both binocular images simultaneously. Avoid this by masking off part of the light which bypasses the binoculars and goes directly through the telescope. Or move the telescope enough to remove the telescopic image of the moon from the field of view. If not overdone, this will not degrade the binocular images significantly.

2) It may initially be difficult to get the binocular images into the telescope's field of view, but a bit of practice soon makes this routine. Low powers help. Also, resting the binoculars against the inside of the telescope tube helps hold them steady.

3) Unless the binocular's barrels are also parallel to the hinge which connects them, a change in eyepiece separation will result in a change in collimation. The collimation may differ for observers with different interocular spacing.



I hope that those who observe with binoculars find this technique useful. It offers the potential purchaser, maker, or owner (or perhaps "headache victim") a means to accurately determine the collimation of his binoculars without special equipment.

Roger W. West
College of Optometry
Northeastern State University
Tahlequah, Oklahoma 74464

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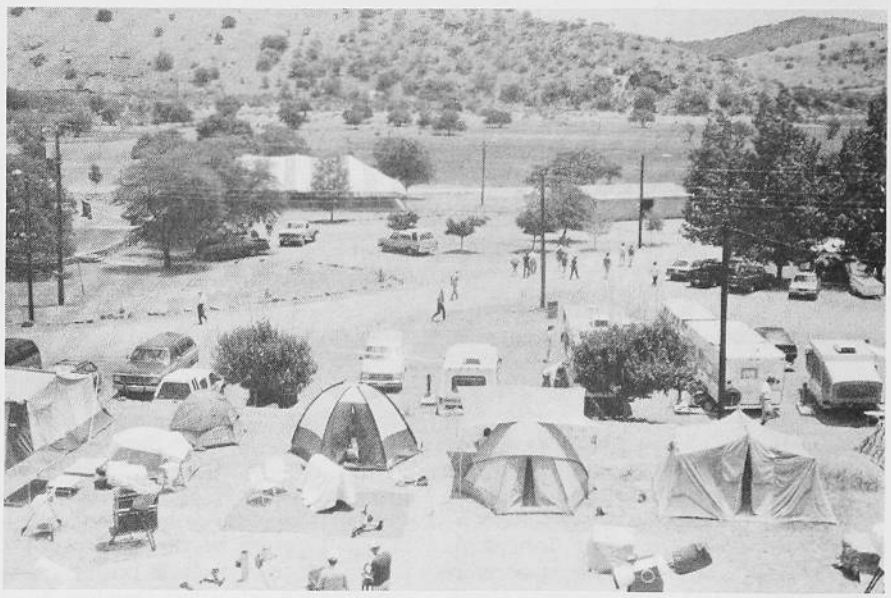
2. Ingalls, A. G. The amateur astronomer, *Scientific American*, 1951, 185 (4): 81-83.

3. Johnson, B. K. *Optics and Optical Instruments.* Dover Publications, Inc., New York, 1960.

Texas Star Party Establishes Itself as a TM Powerhouse



Since its beginnings over a decade ago, when it was just a gleam in Debbie Byrd's eye, the Texas Star Party has grown into one of the largest amateur astronomy gatherings in the country. This year's TSP, held the week of May 21st at the Prude Ranch in Ft. Davis, Texas, was the largest yet. Set under the darkest skies in the continental United States and virtually in the shadow of McDonald Observatory, this year's event drew a record 650 attendees.

Usually, I attend the TSP as an astrophotographer and make use of the terrific dark skies to do sky shooting in its primeval form—that is, without light-pollution filters. This year, however, *Telescope Making* asked me to look at the Texas Star Party from a telescope maker's viewpoint, so this is the story of the Texas Star Party as seen through my often sleepy eyes.

Inside every serious amateur astronomer lurks a frustrated telescope maker harboring a lingering desire for improved equipment or better techniques. National gatherings like the Texas Star Party are the best place to see how the experts use innovation and ingenuity to solve problems with their equipmen. Telescope makers have an openness about sharing ideas that is rare in technical fields.

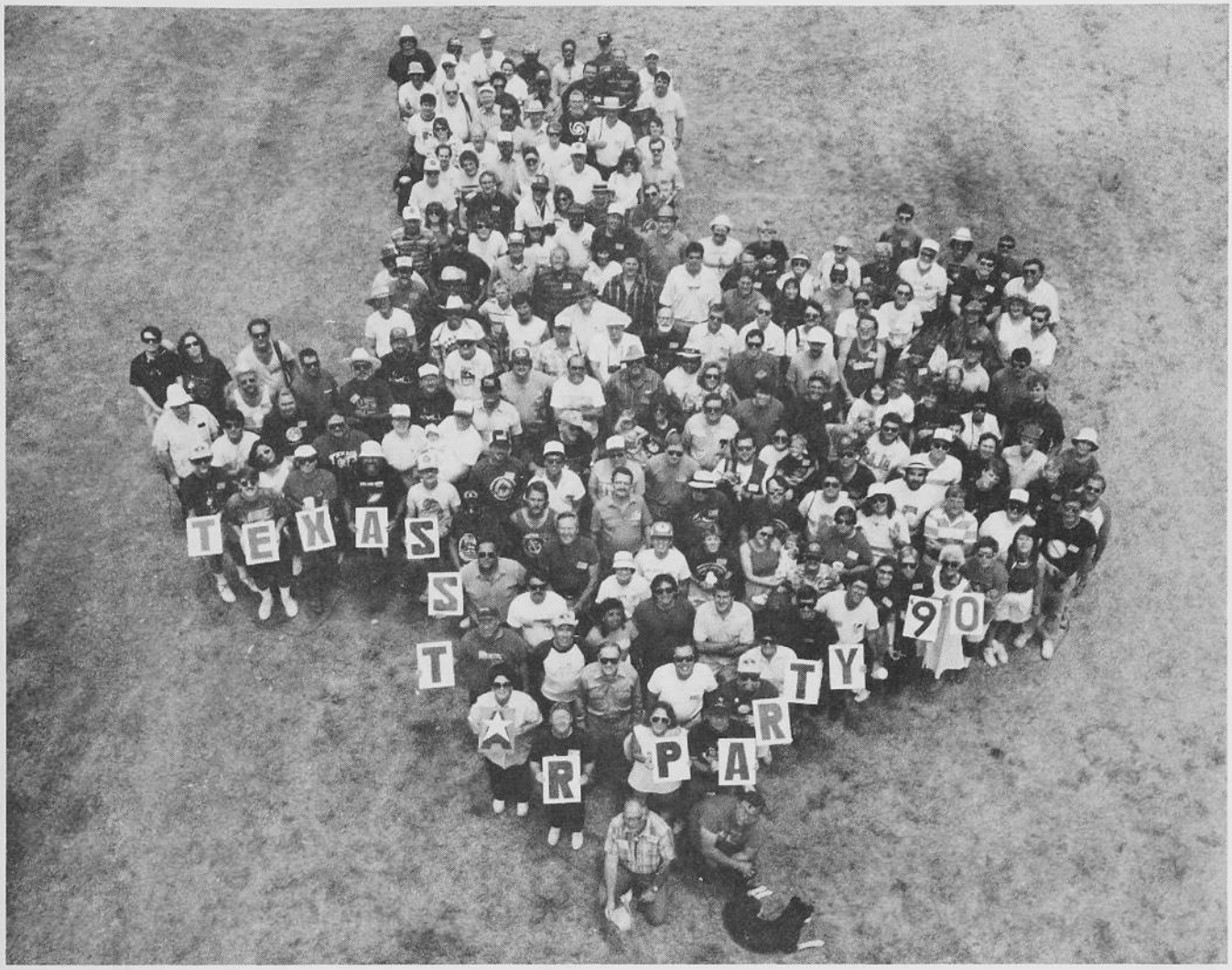
In recent years, telescope-making exhibitions have evolved into one of the major TSP events. At the current rate of growth, the TSP will soon rival Riverside and Stellafane conventions for strength in the telescope-making field.

One item that quickly caught my eye was the proliferation of double-barreled telescope mounts. Three years ago, I brought my Schmidt camera rig to the TSP. It consists of an 8-inch Schmidt camera and an 8-inch SCT telescope mounted side-by-side on a medium-duty German equatorial mount. This year, I couldn't help but smile as I saw many instruments with similar twin mounts.

I saw so many telescopes worthy of mention at this year's TSP that it is with some degree of guilt that I realize space is not available to mention them all. One scope in particular, built by Walter Farrar from Mountain Park, New Mexico, captured my imagination when I literally bumped into it in the night. Unfortunately, when I went back to it the next day to get some photos, it was gone!

Farrar's telescope was a solidly built 17.5-inch f/4.5 classical Dobsonian with Coulter optics. The telescope was equipped with a rotating three-eyepiece turret and a built-in 2-inch Barlow. The Barlow, which Farrar said he salvaged out of a theodolite destroyed in a missile explosion 30 years ago, rendered an amazingly well-corrected field as I cruised the Virgo Cluster.

As good as the view through Walter's telescope was, the instrument's main feature protruded from the rocker box. Mounted on an extended bracket and coupled with the telescope's azimuth axis by two 8-inch sprockets and bicycle chain was a fascinating armillary sphere. This device is actually a mechanical analog computer. A simple dime-store,



If the scenery doesn't tell you you're in Texas, then the participants will. Although an observer's event, telescope making is growing at the TSP.

battery-driven, quartz clockwork mechanism keeps the right ascension setting circle set to sidereal time while the bicycle-chain mechanism keeps the armillary sphere assembly aligned with the telescope as it rotates in azimuth.

Farrar showed a similar armillary sphere device mounted on a 6-inch telescope two years ago and told me he built this telescope to prove the armillary sphere could be mounted on any kind of telescope. He further said he wanted to show that $15 worth of parts can do the job of a $500 computer for accurately pointing the telescope. I will vouch for the system; it was deadly accurate in picking up deep-sky targets.

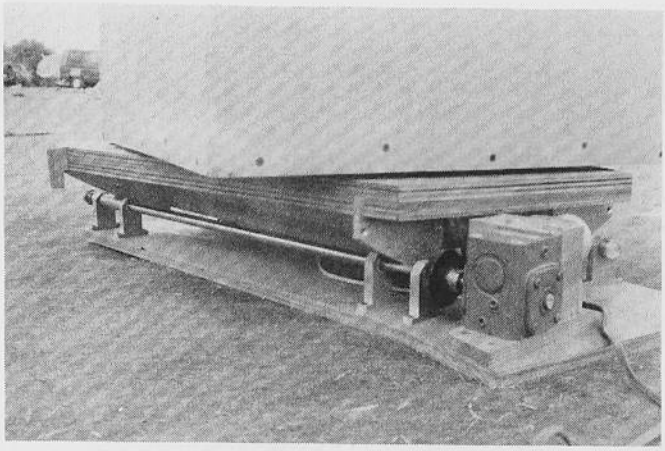
Other scopes displayed outstanding attention to detail. Steve Watkins, of Houston, Texas, machined all the parts of his beautiful 13.1-inch f/4.5 German-equatorial Newtonian. It included a rotating tube assembly and electric focus. I was impressed with Steve's method of one-man collimation. Shafts mounted on the inside of the tube run from the front of the telescope back to the mirror cell to turn the collimating screws. By inserting a screwdriver-type nut driver on the rods at the eyepiece end of the scope, he can adjust the telescope's mirror cell while looking through the eyepiece.

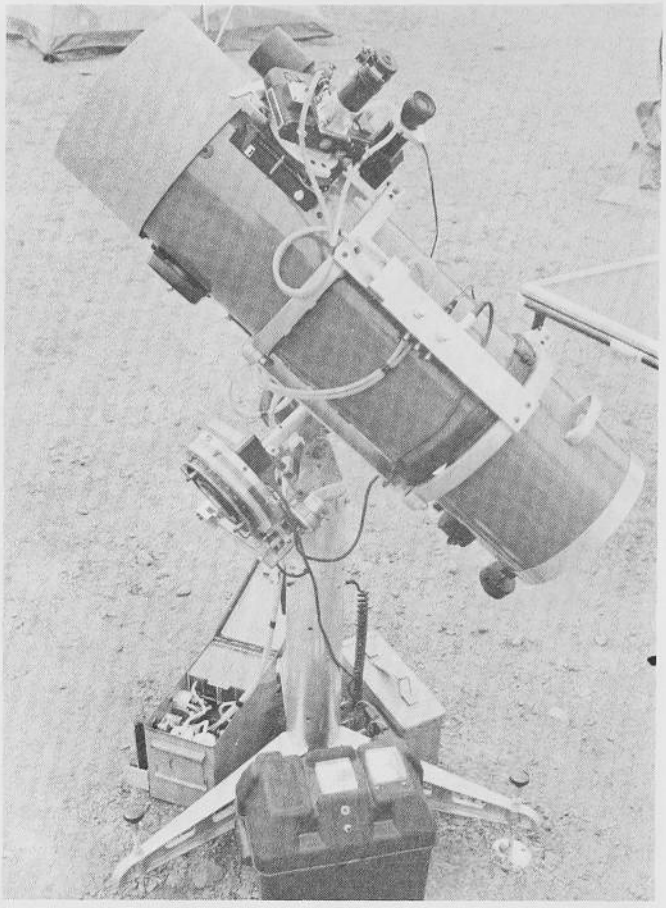
Another instrument built by its owner and fully machined was the amazing 8-inch f/4 astrophotographic Wright-Newtonian displayed by Alabamian Bill Harris. Although the scope was built in 1980, each year Bill relishes in showing off the latest improvements on his instrument. The telescope itself is actually just one component of an extensive astrophotography system Harris has assembled. The telescope looks like some sort of medical device with an intimidating array of power lines running anti-dewing and illuminating devices as well as vacuum and dry air supply lines running to the camera.

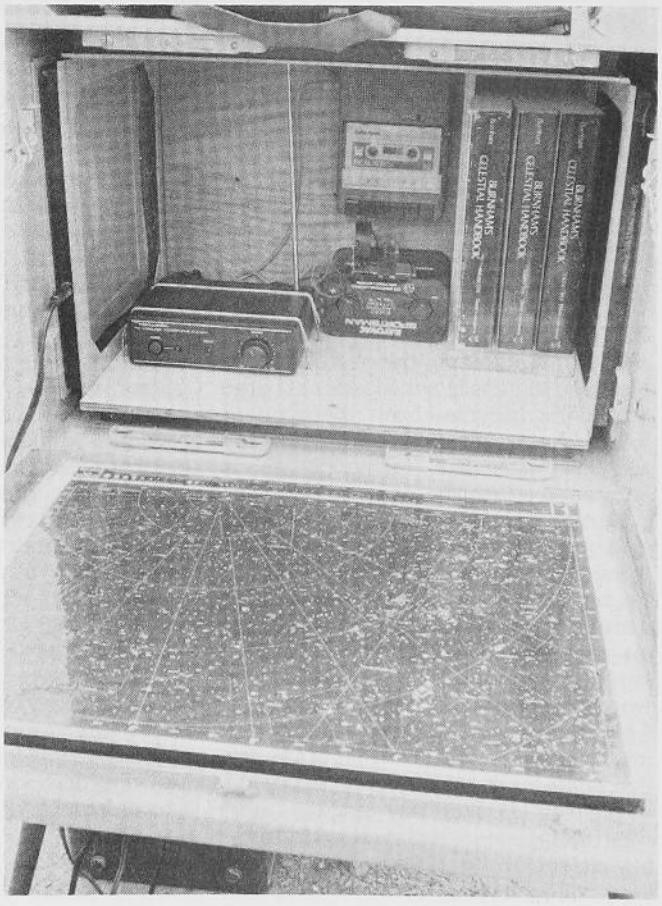
The biggest of the homemade guns at this year's TSP was Kenneth and Paula Drake's 24-inch f/5.6 Dobsonian, christened "Vertigo 1." In an all-too-familiar pre-star-party crash project, Kenneth built the 24-inch entirely in the week preceding the TSP. Equipped with a Paul Jones mirror, the instrument saw first light at the Prude Ranch.

Another of the big guns was Barbara Wilson's 20-inch f/4 Dobsonian. Barbara was particularly proud of the "polar roller" tracking platform under her scope, which was built for her by Andy Sauleitis of Houston. A modification of the Poncett design, the platform uses a driven steel shaft rolling under curved steel plates to track for an hour before limit switches shut it off. A clutch and crank allows her to reset the drive in a matter of seconds.

Steve Linscott of Houston really



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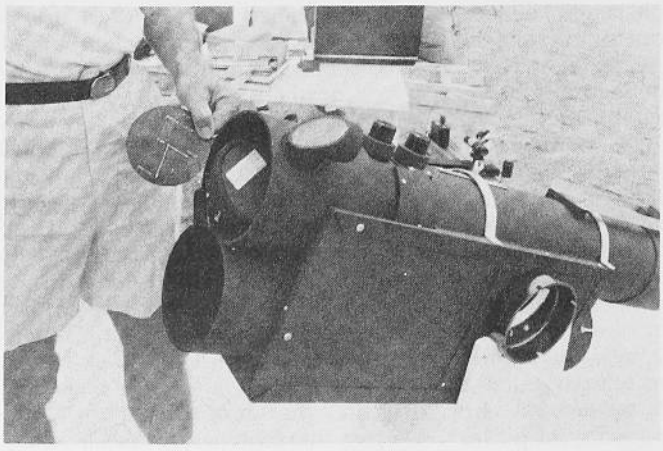


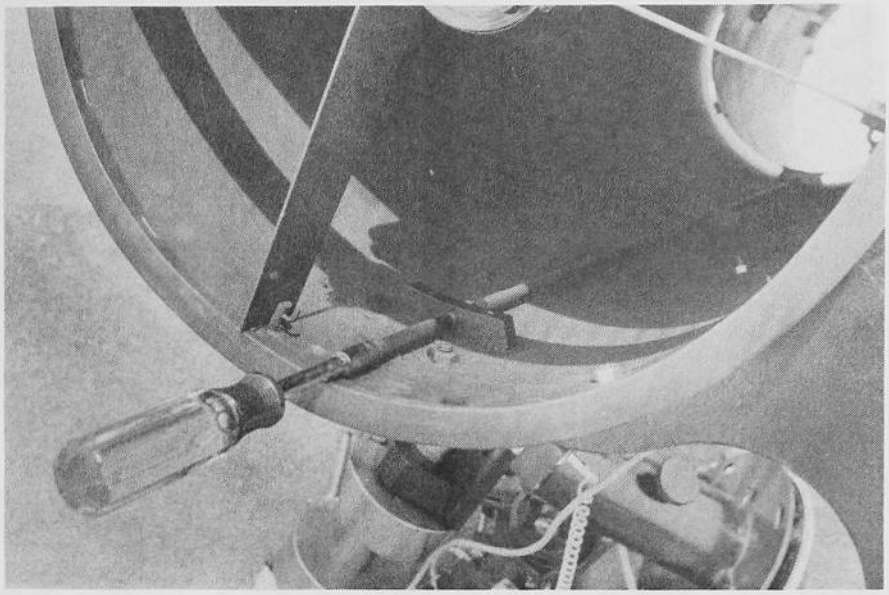
"gets wired" when he goes observing. Steve has assembled an unusual observing box. In addition to the usual charts and accessories, the box also contains a voice-activated tape recorder which responds to a wireless microphone he wears at the eyepiece. In this manner, Steve effortlessly logs all his observations. When the recorder reaches the end of a tape, it even sounds an audible alarm.

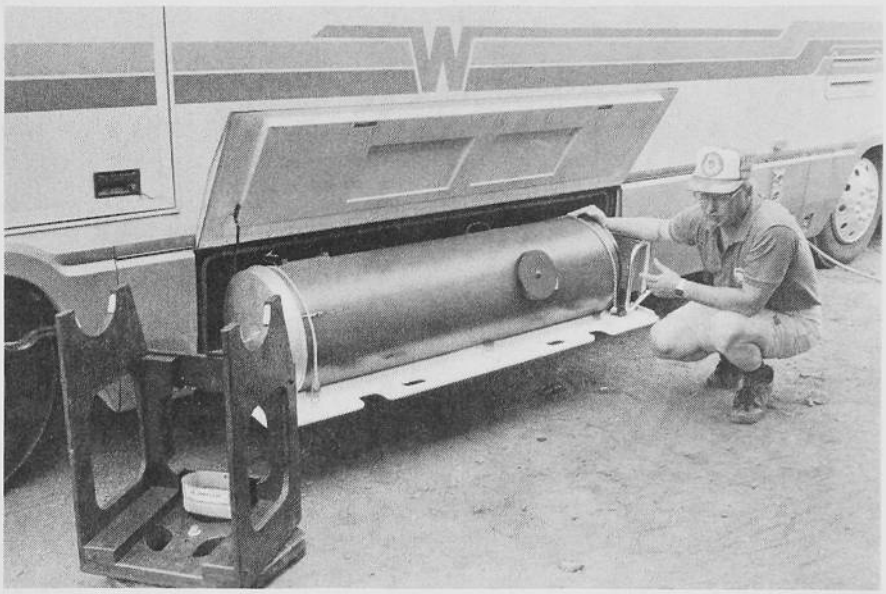
In the field of pure innovation, Peter Wraight, also from Houston, has designed a novel piggyback binocular telescope. Displayed in both 4.25- and 6-inch versions, Peter's scope sidesteps the conventional binocular design of side-by-side Newtonians and stacks the two scopes vertically. The image reflected from the secondary of the lower telescope passes through the tube of the upper telescope on its way to a second eyepiece mounted on the upper tube.

Many other fine instruments demanded a second look. These included the trailer-transported 18-inch f/4.5 fork-mounted Newtonian shown by Edward Szczepenski from Houston. Wisconsin's Peter Smitka showed a crowd-pleasing 18-inch f/5.5 Dobsonian. One of its features was an illuminated Astro Card holder beside the eyepiece. David Lee from Dallas designed an innovative transformer mount for his small rich-field telescope. Designed around a 300mm focal length f/5.6 Zeiss lens, the Dobson-type mounting for this little telescope breaks apart to be reassembled as the instrument's carrying case. This type of mount can be adapted to small solar eclipse-chasing telescopes.

Although Winnebago motor homes usually can't be classified as astronomical equipment, Jim Kube from Milwaukee would argue the point. Jim has converted a lower luggage and storage bay under his motor home into a slide-out transporter for his 13.1-inch Odyssy telescope. Accessed from the outside of the motor home, the telescope can be set up in minutes.

Running on rollers, Barbara Wilson's 20-inch Dob showed promise for equatorial platforms. The tall telescope belongs to Kenneth and Paula Drake; it's a 24-incher with an f/5.6 mirror. At the lower left is Peter Wraight's binocular. Bill Harris showed his rig, and everone envied Steve Linscott's observing box that keeps what he needs ready for use.





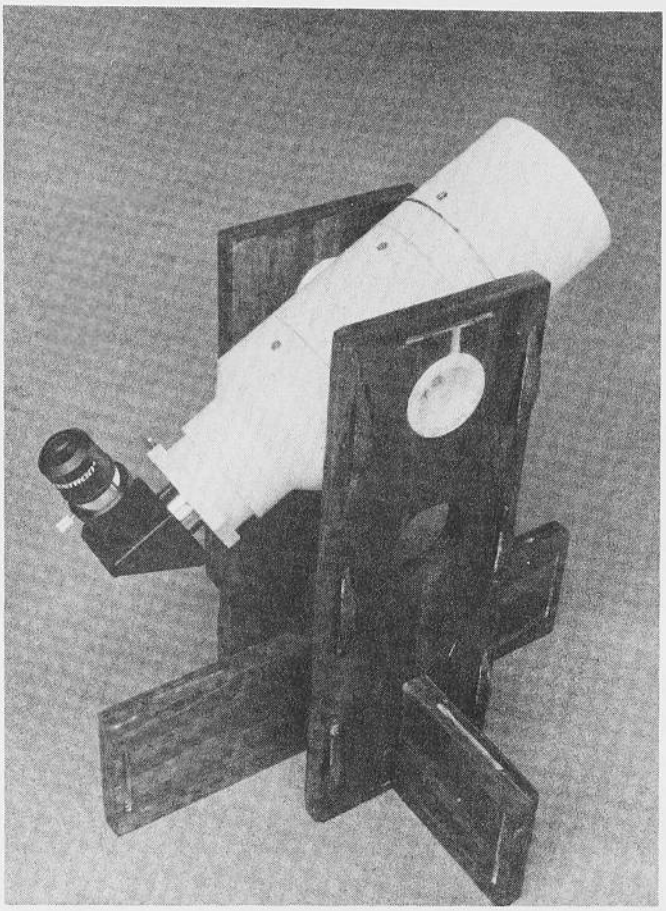
Although TSP legend decreed this year was supposed to bring clear weather, there were periods of cloudiness on most nights of the star party. One such cloudy period found me on the north end of the observing field by the monolithic 24-inch f/5.6 Dobsonian owned by Kenneth and Paula Drake from Houston, Texas.

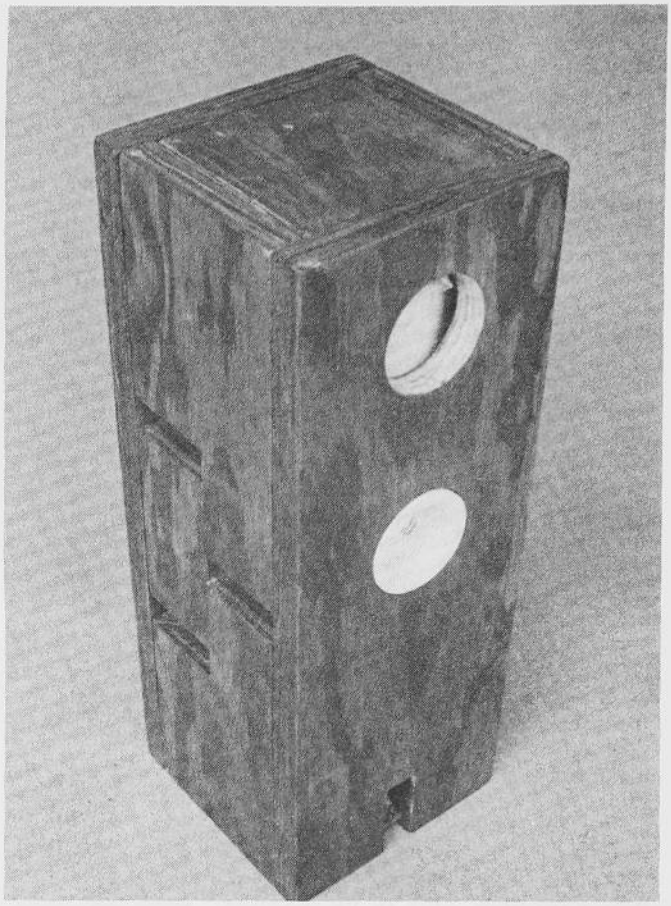
Other ATMs gathered around the massive 24-inch telescope were engaged in a conversation about what makes telescope makers tick. Joining Kenneth were Peter Smitka and David Kriege from Wisconsin and Peter Wraight from Houston, Texas. Because I'm from another branch of amateur astronomy, I was interested in how telescope makers view astronomy. Here are some of the highlights.

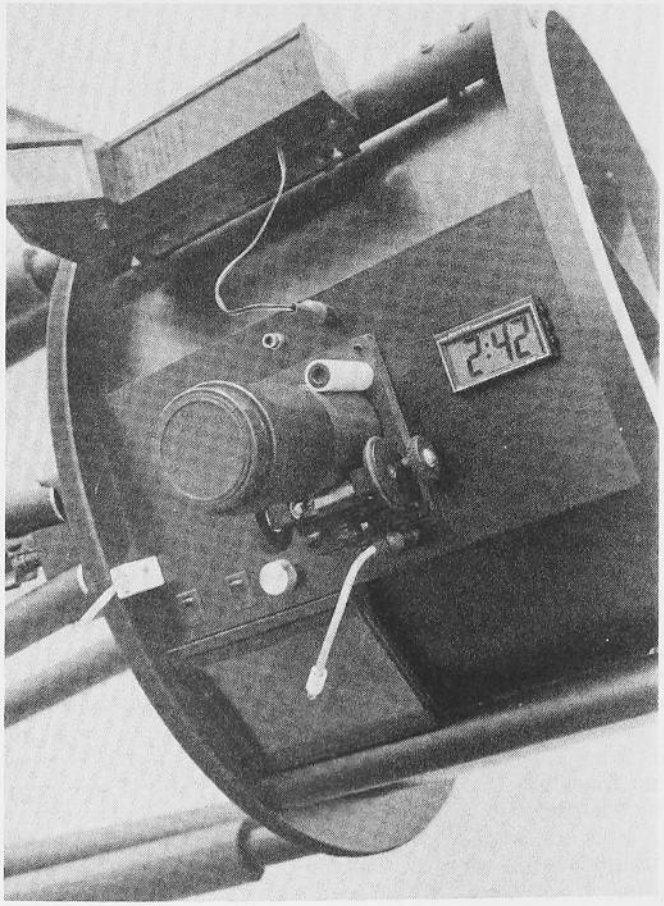
Steve Watkins cuts the hassle of getting coma-free images with collimation rods. Below: Jim Kube unloads his Winnebago telescope carrier.

Smitka: "I like building telescopes, but I am also a telescope user. I like to observe. To me, the sheer joy of making something with my hands, and then using it to look at something that is visually pleasing, is the reason I am in this hobby. We are in it for fun! I get ticked off when someone asks, 'Are you taking pictures or making records?' Hell no! It's like when I play tennis, I keep score only until the end of the game. I don't remember what the heck I did two months ago and I don't care. I play for fun."

Kriege: "I enjoy making telescopes



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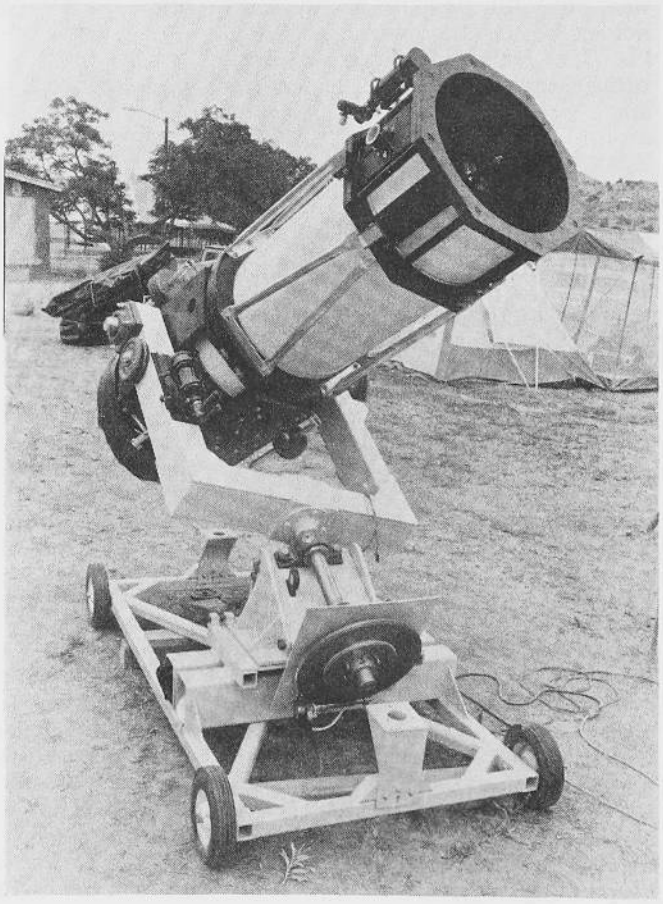


also, but I enjoy observing more. I know what I want the telescope to do. I don't like wiggly images and I like a lot of light gathering. I want a big telescope that moves easily and is quick to set up. I am constantly thinking, 'How can I make this better, how can I change this.'

"I spend a lot of time in hardware and surplus stores to find things. TMs can look at a pile of cast-off junk parts and see them as telescope parts. I have a whole basement full of 'telescope parts.' For a lot of the things we use in building telescopes, there are no books on them."

Wraight: "With telescope building, you don't really know what you are going to do next. You have to invent as you go along, and that is the pleasure I see in it. If we always think someone else has a bigger scope and it's no fun if we build something smaller, then we wouldn't do anything. I think it is important that I don't feel intimidated that everyone else has these enormous telescopes. That doesn't detract from my personal pleasure. But remember, it is a hobby. Whatever gives you pleasure and satisfaction, that is what is important. You have to get that kick in the heart, and you should feel proud of it. That is why we do this."

Smitka: "I think too many telescopes end up gathering dust because they are too complicated to use. If you can set up a telescope in a few minutes and be observing, then you will use it. That is what the telescope is for, to put star light in your eye."

Kriege: "It would be foolish to make a telescope bigger than a 25-inch. It wouldn't be portable, so why do it? I am already seeing things the astrophotographers have to shoot for an hour to see."

Smitka: "Today the optics are so good and reasonably priced that we can build large telescopes and do visual observing that is as good as hour-long photographs, and we are seeing it live! You look at a globular in a photograph and the central part is always burned out. We are looking at it the way it should be. It's fun, it's really fun!"

Drake: "That is absolutely true! In six seconds, your eye can see what takes hours to photograph."

Smitka: "I have no desire to take pictures through the scope. I want to see the stuff live. To me, taking a picture and guiding for an hour is like the sex in Playboy! It just doesn't cut it!

"I like looking at the sky because it is pretty. There is a certain wonder to it. To me it is also a humbling thing. You look at the light from something that started toward your eyes when there were dinosaurs around. That is part of the fun of having a telescope: using it as a time machine. Building is almost as much fun."

Drake: "Once you see the Veil through a 24-inch, you get spoiled and it's hard to go back! There is a saying, 'Never look through more aperture than you can afford!'"

Smitka: "What I see happening now is people demanding better optics. People have gotten the big optics and now are saying, 'I know it can be better.'"

Kriege: "You want to know what the TMs are going to be doing in the future? Just look at the major observatories. What they are doing now is what the TMs are going to be doing in a few years. It's going to be more and more hands-off. You will collect your data and store it, then look at it on a rainy night."

Smitka: "I expect more people will play with computers. But keeping the eyeball away from the eyepiece does not appeal to me. We have astrophotographers and visual observers now, but soon there will be the third group, the hackers. They won't want to do anything but sit at the keyboard and look at deep-sky stuff on the video display."

Drake: "One of these days, Levy will discover another comet, and immediately amateurs all over the country will jump out with their 18-inch Dobsonians with their stepper motors, encoders, trackers, CCDs, and computerized enhancement devices and verify the comet."

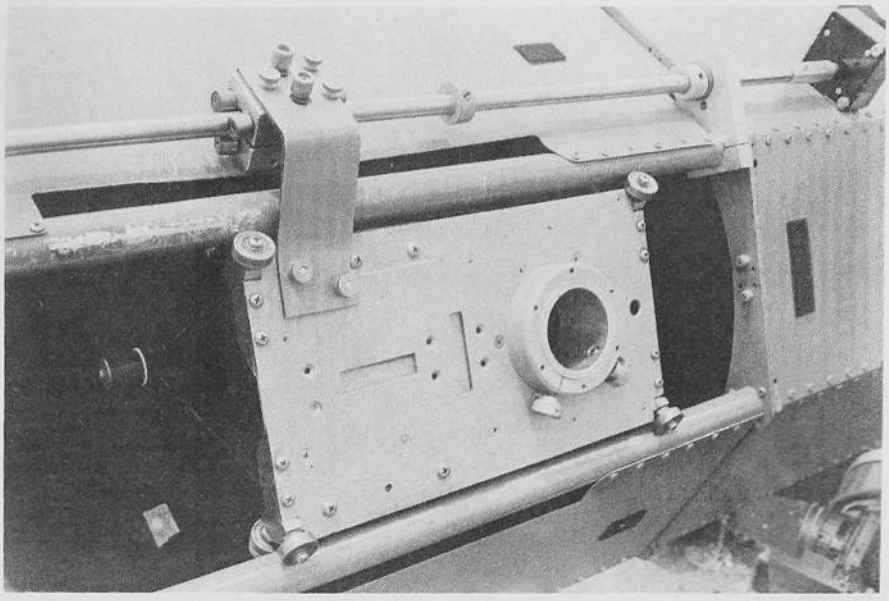
Wraight: "Using a computer to locate objects for you is too cold. You might not even know what constellation the object is in. You should know what you are looking at, its number, and its history. It should not be just a fuzzy blob; it should have a personality."

Smitka: "I want to voice one major concern I have about our hobby. If you look around here at the TSP, you don't see anyone who is 18 or 19 years old. Most people are in their 30s and 40s. It has gotten to be an expensive hobby."

Support for telescope making continues to grow each year at the Texas Star Party. As the equipment displayed under the Texas skies testified, the Southwest is rapidly becoming a powerhouse in the telescope-making field.

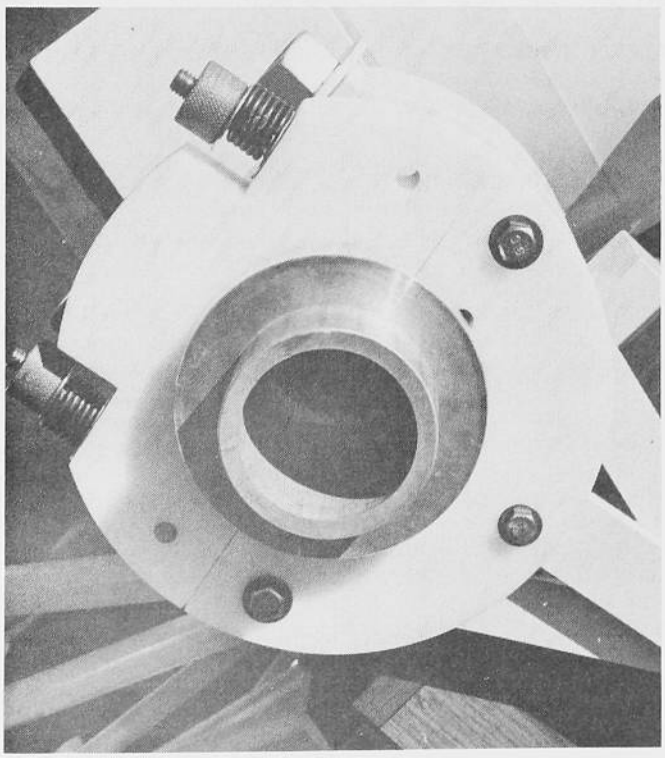
Move over Riverside. The Texans are coming!

—Robert Reeves

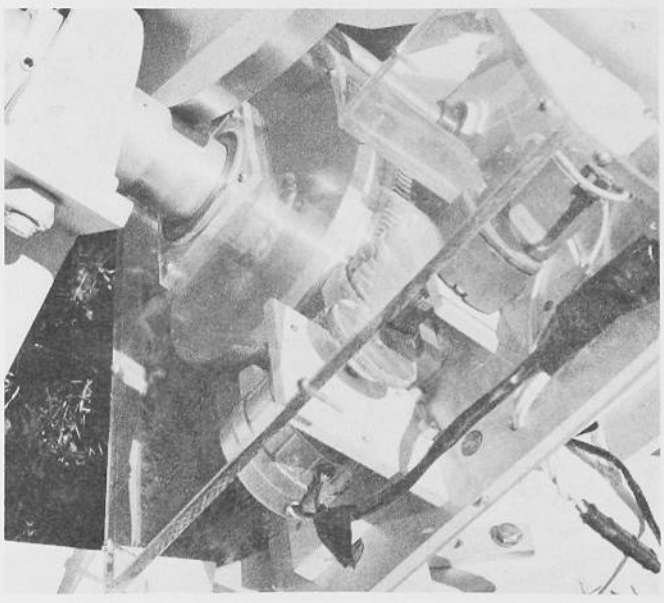


David Lee's breakapart telescope mount and carrying case shown here packed and ready for use. The scope is built around a 300mm f/5.6 Zeiss lens. Lower left: Peter Smitka's 18-inch Dob sports electric focusing, a clock, and an illuminated holder for AstroCards. Lower right: This solid 18-inch fork-mount built by Ed Szczepanski features a wheeled carriage.

Rollers support Gil Machin's focuser, but inclined rollers pressing against the shaft beside the focuser move the carriage forward and backward.



A big aluminum drive roller, a solid walnut fork, and a lightweight truss tube make Steve Messner's 18-inch Newtonian a pleasure to use. A Mathis drive gear in a Plexiglass housing powers the eastern drive roller.



ASTROFEST 1990

THE BEST EVER

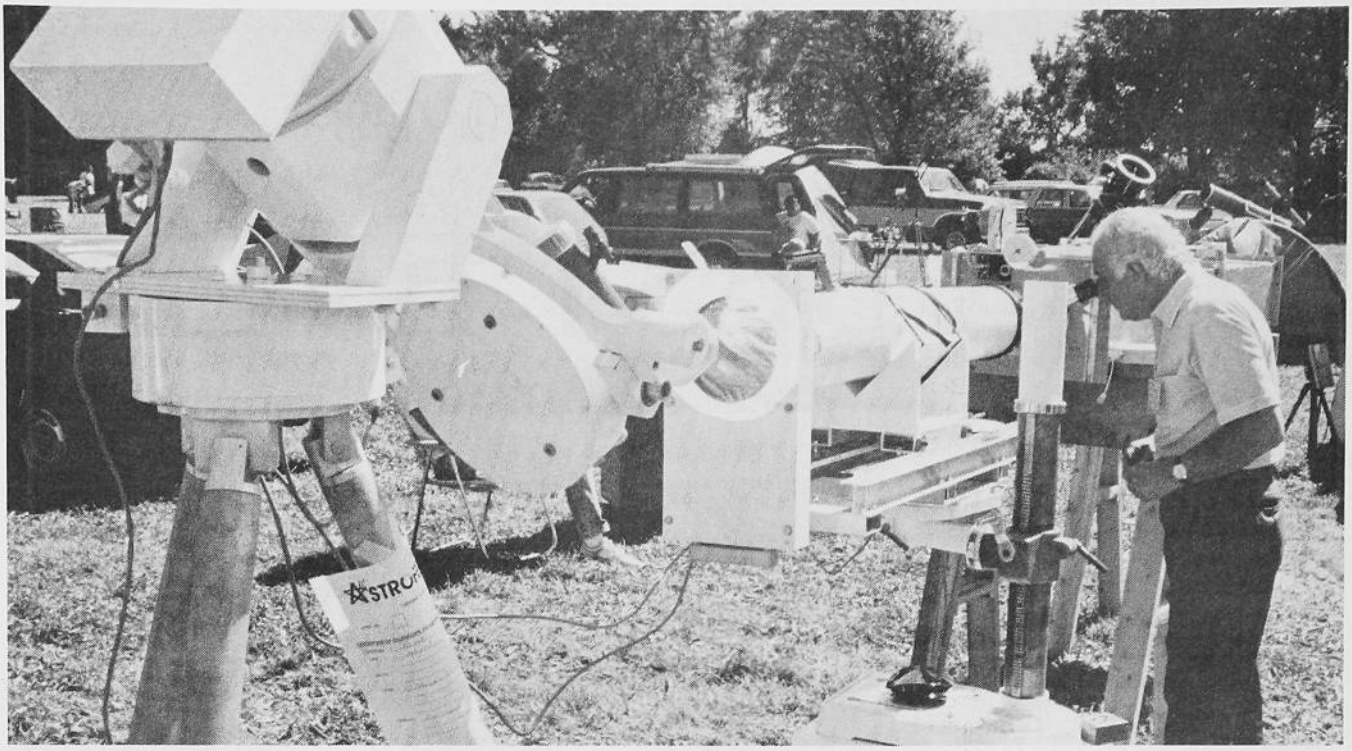
The 1990 AstroFest is sure to go down in history as one of the best. Clear nights and sunny days prevailed—at least when it mattered—and the turnout must have set some kind of record. Then, too, the swapmeet couldn't be beat. I found a big, solid surveyor's tripod for the antique camera lens I bought last year.

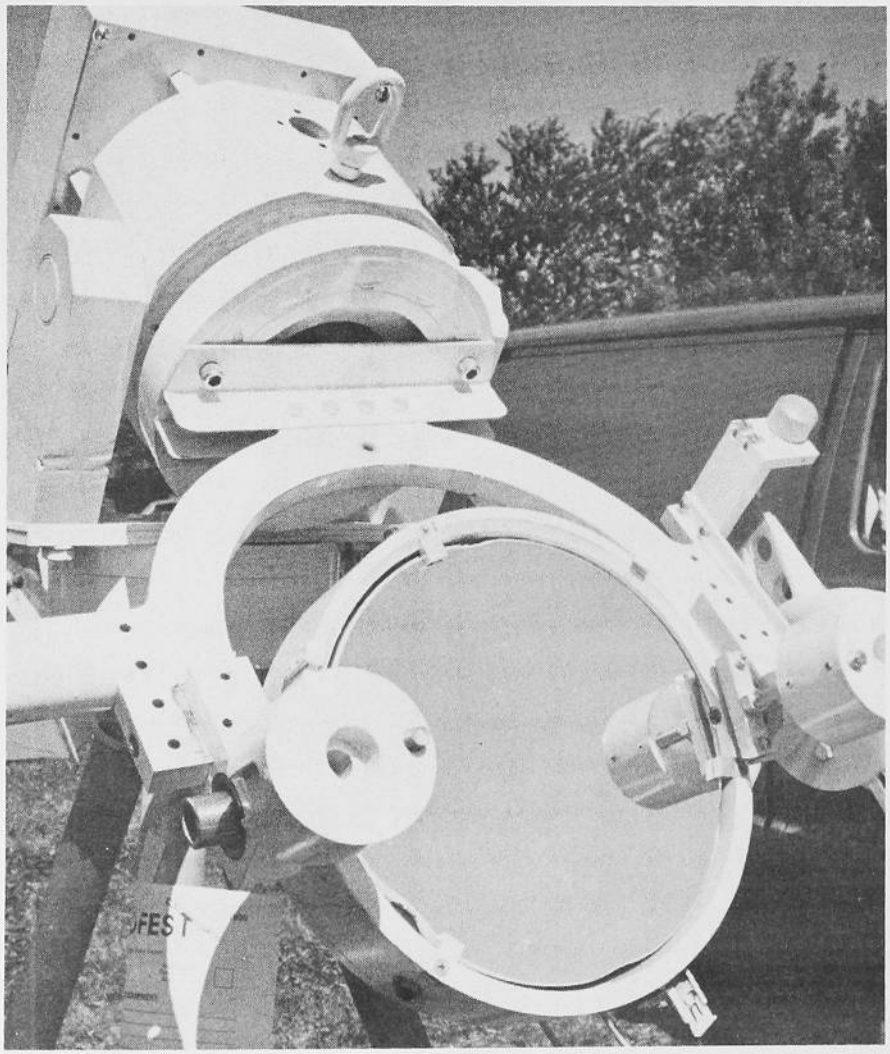
Chicago has always been the biggest obstacle to enjoying AstroFest for me, not so much for anything about Chicago, but the fact that Chicago lies between Milwaukee and Kankakee and has to be driven through. (Actually, it's possible to avoid Chicago, but it's not very direct.) Last year I got caught in Chicago traffic. This year, as I whizzed up to one toll booth after another and threw my 40 cents in the hopper, I couldn't believe my good fortune. There was a smile on my face as I turned into the Camp Shaw-Waw-Nas-See driveway.

To my surprise, the main telescope field was already quite full. Three long rows of cars and campers stretched the length of the field. In front of each row of vehicles were tents, tables, and telescopes. People were looking at telescopes, taking pictures, and laughing and talking with one another. Because I did not have a telescope, I parked in the lot, under the trees, so that my van would not become too hot during the day.

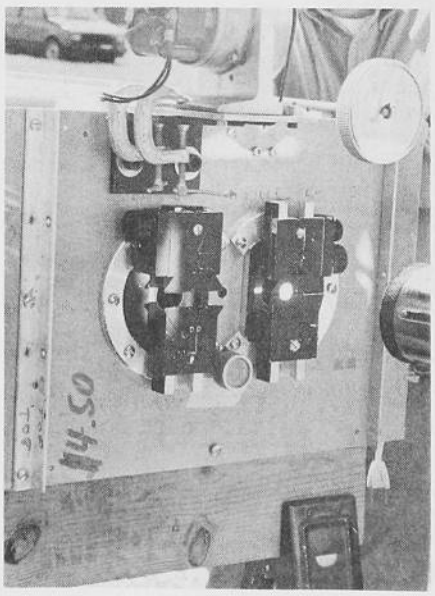
In other years I've taken telescopes to AstroFest, but this year I had something different: a computer. Since the IAPPP meeting in May (see *TM#41*), I had been hacking away at an image-processing

Boasting a near-stationary eyepiece, Dick Wessling's 8-inch f/20 Buchroeder tri-schiefspiegler gives high-power viewing in a compact box.





Eighteen years in the making, Wally Piorkowski's solar observatory was set up for the second time ever this year at AstroFest. The system has a 10-inch heliostat, a 5-inch f/10 AstroPhysics refractor to form an image of the Sun, and a 6-foot spectrograph. The spectrograph provides a spectrum that is 33 inches long, from the ultraviolet to the infrared, and Wally has taken pictures of the spectrum with it. Wally has the optics to use the spectrograph as a spectroheliograph with rotating Anderson prisms for a bright flicker-free image of the Sun in H-α light.



program, and I had some pretty neat stuff to show for the effort. But more about that later.

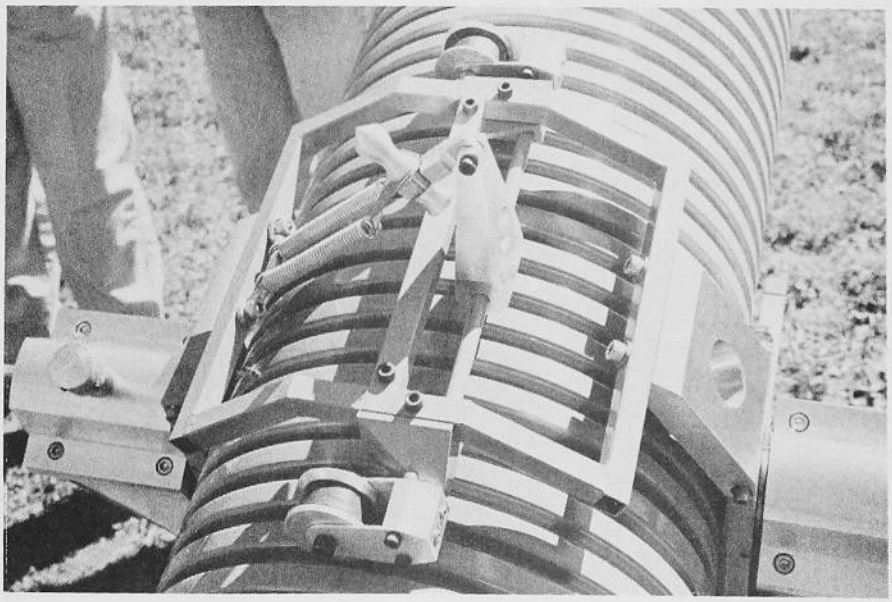
The meeting hall was as busy as the telescope field. I got my badge and cabin assignment. The Chicago Astronomical Society folks who run the convention were there. For Al Birkner and Jon Nehls it looked pretty hectic. It's easy for those of us who "go to" events like AstroFest to forget that AstroFest doesn't just happen. Yeat after year, people like Chris Hansley, John Phelps, Bert and Janet Stevens, Carl and Debbie Buzzard, and the other members of the 'Fest committee put in a huge amount of work to make this event go. We owe them a lot for a fine meeting, one of the very best.

After walking around the field to see what was up, I buzzed off to town for a bite to eat. The sky looked promising, and I expected to put in a long night's observing.

When I got back, I started across the telescope field—and bumped into Don Parker. Don lives in Miami and takes advantage of the superb seeing there to shoot some of the best planetary photographs in all of amateur astronomy. A few weeks earlier, Don sent me some planetary photos and I digitized them with a Lynxx CCD camera. And then I ran an unsharp-masking routine on them using my image processing program.

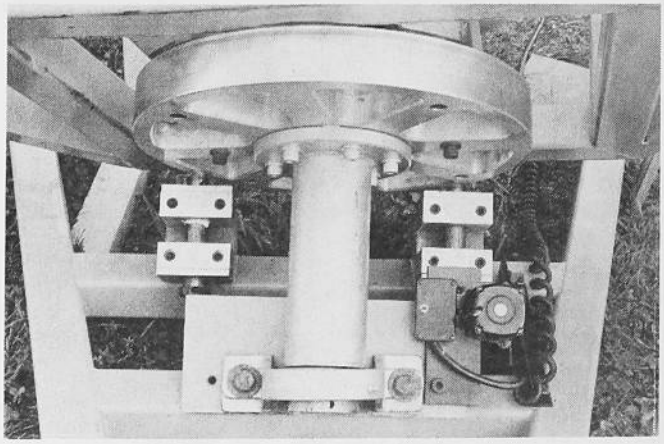
Don and I went back to my van and hauled the computer, monitor, and disks full of images over to the main lodge. We borrowed a power cord and wiped the greasy remains of someone's pizza feast off the table. Don's eyes lit up when he saw his pictures on the computer screen, then got wider and wider as we enhanced the zones and belts.

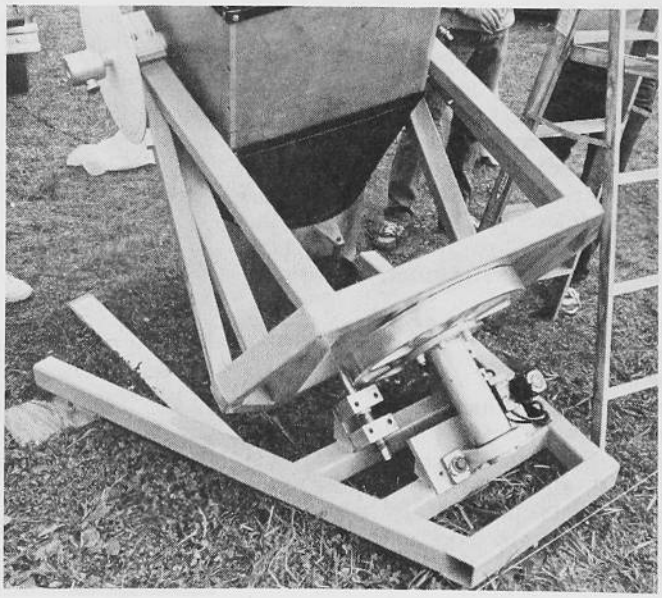
I think that CCDs will become very important for planetary imaging in the next ten years. I got carried away, and said something like this to Don: "It doesn't take many pixels to capture the full resolution of the telescope. If you enlarge the image to 1/4-arcsecond per pixel, then the biggest planet, Jupiter, is



A tube that begin life as a sewer pipe eventually became a fine telescope with the help of telescope-builder David Jucken. The telescope is a work in progress, still without a drive, but David's marvelous spring-loaded clamp for the tube (see closeup) is a work of art. David learned how to work with resin and fiberlass from building aircraft.

Polar roller drives appeared twice under a large telescope at this year's AstroFest. Dan Joyce's .5-meter reflector (that's 20 inches for you plebians) featured fine optics, excellent tracking, and a very solid fork mounting.





Bob Bunge stands beside Frank Hudnall's vintage-1952 pipe-mount 6-inch f/11. Below: Paul Moffat with his huge wooden polar disk mount.

typically only 160 pixels high by 150 pixels deep. A camera like the Lynxx can digitize that image with a photometric accuracy of about 0.1%, which is far more accurate than photographic film. Because CCD chips are small, the planetary image can be small. At 12-inch telescope working at f/30 will give the right image scale. Your exposures can be short, maybe a tenth of a second, so you'll freeze the seeing."

What a mouthful! I gave Don a copy of the program (called Image-Pro) and promised to digitize more of his photographs. You'll see one the results of our little collaboration in the February ASTRONOMY.

The swap meet began the next morning at 7:30. By the time I went for coffee and donuts, I had the distinct impression that the best goodies had already been sold. As luck would have it, no one else wanted the hefty surveyor's tripod that I bought for the 8x10 view camera I built around an old Petzvel portrait lens I bought the year before. I also got a heavy-duty fiberglass carrying case for eyepieces, and some interesting old books.

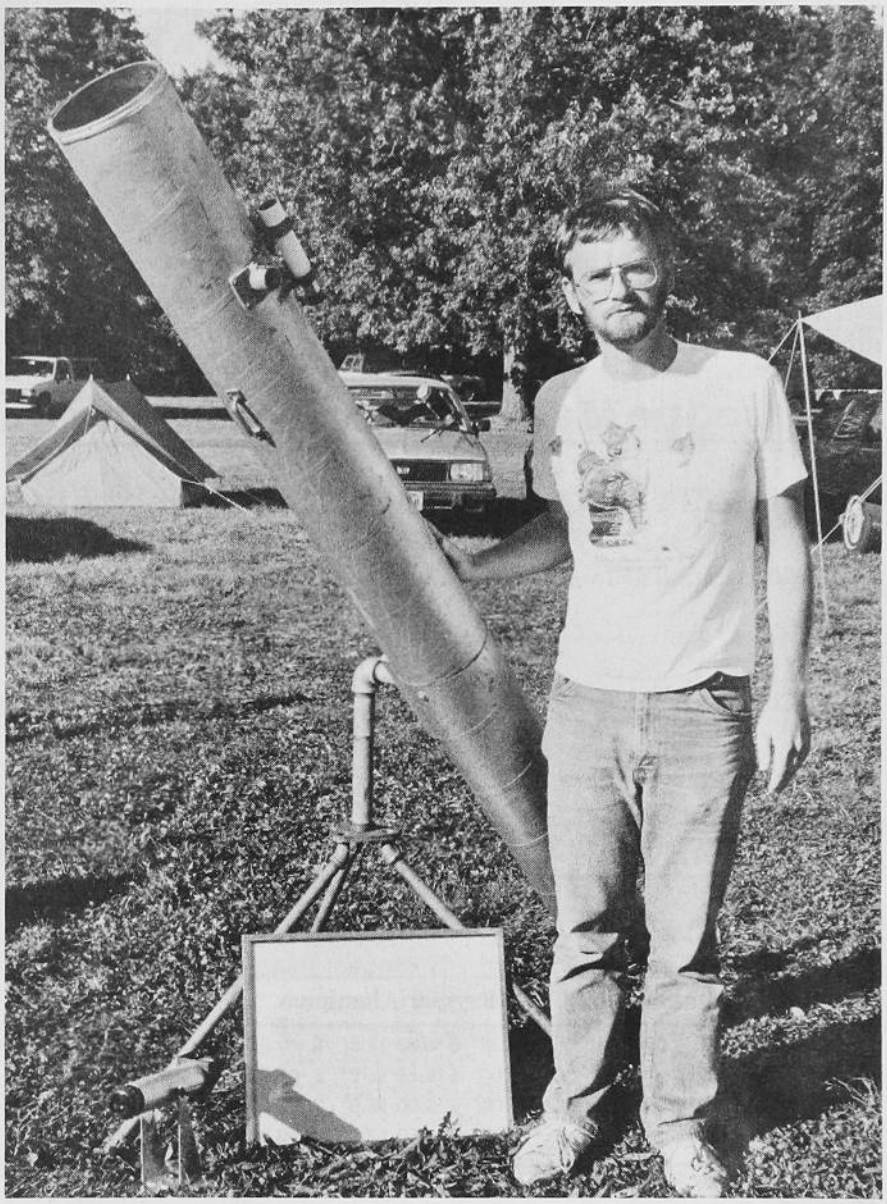
Out on the field, I joined the large crowd hanging around Wally Piorkowski's big solar telescope (see page 40 of this story). Wally didn't have the spectroheliograph running when I was there, but he's going to get good views when he gets it going. Wally is planning to use a 2-inch diameter solar image with it.

Just across the way, Bill Benesch had set up his 13.3 cm f/15 Daley solar telescope. Because the sky was clear this year, Bill had a steady stream of lookers. The Sun was an awesome sight. I could see granulation over the entire solar surface and light bridges cutting across the penumbras of several medium-sized sunspots.

I concentrated on getting some of the pictures that accompany this story that afternoon. Steve Messner's 18-incher and Dan Joyce's 20-incher herald the mini-trend toward roller drives. On the commercial front, the NGT-18 is an outstanding example of this easy-to-machine, smooth, and accurate type of drive.

When I pulled out of Camp Shaw-Waw-Nas-See on Sunday, I knew it had been a great AstroFest.

—Richard Berry



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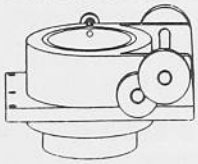

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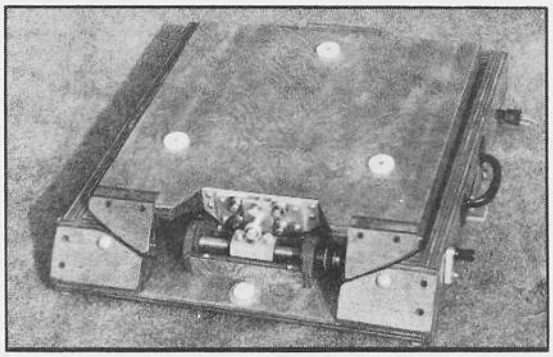

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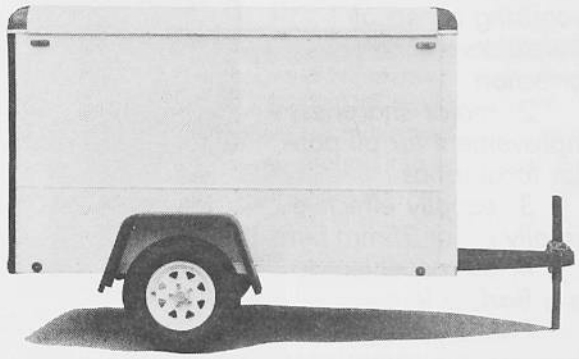

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Coma 1 inch off-axis (17½" f/4.5)

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Filter Type	1¼"	48mm
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Lumicon Deep-Sky	**$79.50**	**$119.50**
Set UHC and Oxygen-III .	**$190.00**	**$380.00**

NOTE: The Oxygen-III Filter is not a substitute, but a compliment to the UHC Filter. **1 year guarantee:** You must see nebulae with the O-III filter that are **invisible** without a filter.

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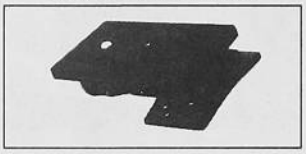

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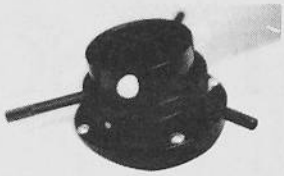

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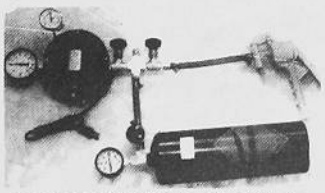

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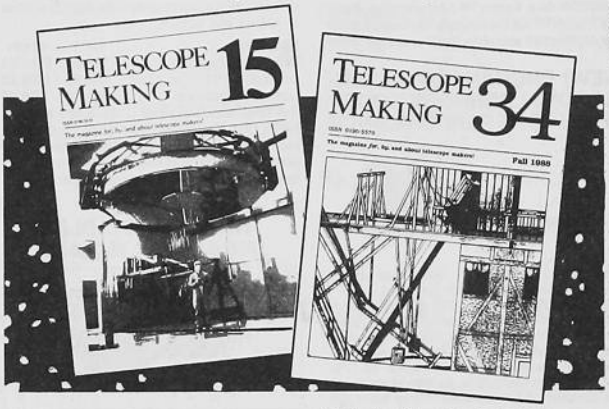

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